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BASE EXCHANGE IN SOIL SEPARATES AND SOIL FRACTIONS (SAND AND SILT)[1]

ALFRED T. PERKINS AND H. H. KING

Kansas Agricultural Experiment Station

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Base exchange phenomena in soils are the zeolitic-like abilities of soils to hold bases against water solution but permit their liberation by exchange with other positively charged ions.

The base exchange capacity of a soil is probably as good a laboratory test of the potential fertility of a soil as is now available. In general, soil chemists believe that the soil minerals possessing the power to exchange bases are chiefly the hydrated alumino silicate complexes and that the base exchange capacity of a soil increases as its colloidal content increases. Kelley and Dore (3) expressed this idea by stating that soil colloids are related to montmorillonite and that the replaceable base content may be increased several fold by grinding certain minerals.

The soils used in this investigation were Wabash and Summitt, which are relatively fertile, and Derby and Cherokee, which are relatively unfertile. The soils were treated with 6 per cent hydrogen peroxide to destroy all organic matter, and the residue was moistened sufficiently with water to form a thick mud and manipulated with the hands until all microscopically visible aggregates were broken down. Repeated treatments of this nature, as the separation progressed, were needed to insure the complete destruction of all microscopically visible aggregates. The soil was finally agitated in water at 25° in a large hydrometer jar and permitted to settle for $6\frac{2}{3}$ minutes for each 2 feet of depth. The supernatant suspension was syphoned off and the residue reagitated and allowed to resettle. This process was repeated until the supernatant liquid was apparently clear, after which the precipitates were collected. Other separations were made with sedimentation periods of 40 minutes, 4 hours, 24 hours, and 6 days. The entire scheme of separation and subsequent fractionation is outlined in table 1. The fractionations were made according to the specific gravity of the soil particles. The separates were suspended in a carbon tetrachloride-bromoform mixture, adjusted to the desired specific gravity, and centrifuged. The finer soil separates were moistened with carbon tetrachloride and placed in a high vacuum to remove all absorbed air, which would tend to reduce the apparent specific gravity of the particles.

[1] Contribution No. 210, department of chemistry. The data in this paper were presented at the Kansas City meetings of the American Chemical Society.

This laborious system of obtaining the soil separates was used in preference to an elutriating device, as it enabled one much more readily to watch the process of separation, facilitated the working of the soil to break down the aggregates, and made possible a more accurate separation of the particles at the desired points. An elutriating device will probably be used, however, in the future work.

The general trend of base exchange phenomena in the soils studied is indicated by the data given in table 2. It should be noted that such sedimentation periods were selected as would result in the various separates decreasing progressively by approximately 50 per cent in diameter. It is obvious that as the size of the particles becomes smaller the base exchange capacity of the separate increases per unit weight but decreases per unit of surface area. This agrees with work published by Perkins and King (4). According to the

TABLE 1

Soil separates and soil fractions

SOIL SEPARATES			SOIL FRACTIONS OBTAINED FROM SEPARATES		
Suspension time	Sedimentation time	Separate	Specific gravity		
			Minimum	Maximum	Fraction
.....	6.67 min.	A	...	...	.....
6.67 min.	40.00 min.	B	X	2.0	2.0–
40.00 min.	4.00 hr.	C	2.0	2.4	2.0–2.4
4.00 hr.	24.00 hr.	D	2.4	2.6	2.4–2.6
24.00 hr.	6 days	E	2.6	X	2.6–
6 days	.....	F	...	...	.....

A Wabash C 2.0–2.4 fraction is the Wabash soil minerals that will remain suspended in 2 feet of water at 25°C. for 40 minutes but will settle out in 4 hours and have a specific gravity between 2.0–2.4.

American System of mechanical analysis of soils the A separate would be sand, the B and C separates silts, and the D separate would be on the border line between silt and clay. According to the International System the A and B separates would be sands, the C and D separates silts, and the E separate would be on the border line between silt and clay.

The base exchange of the individual fractions of the soil separates was also studied. The data for the various fractions are presented in table 3. We note that in considering the A, B, C, and D separates the fractions with a specific gravity between 2.0 and 2.4 possessed a greater base exchange capacity than did the heavier fractions, but the difference decreased as the particles became smaller. In the A separates the fraction with a specific gravity between 2.0 and 2.4 possessed 41.5 per cent of the base exchange capacity of the entire separate even though it comprised only 9.6 per cent of the separate. As the particle size of the separates became smaller to the base exchange capacity

per unit weight became greater. In considering the 2.0–2.4 fractions alone, however, the base exchange capacity remained practically constant per unit

TABLE 2

Base exchange capacity of soil separates

(Average of Wabash, Cherokee, Derby, and Summitt soils)

SEPARATE	AVERAGE DIAMETER	BASE EXCHANGE CAPACITY PER 100 GM.	BASE EXCHANGE CAPACITY PER 100,000 SQ. CM. SURFACE*	SEPARATE, PER CENT OF ENTIRE SOIL	BASE EXCHANGE CAPACITY OF SEPARATE, PER CENT OF BASE EXCHANGE CAPACITY OF SOIL
	mm.	*m.e.*	*m.e.*		
entire soil	?	16.39	?	100	100
A	0.0560	6.36	15.23	28.2	11.61
B	0.0283	6.23	7.74	28.3	10.75
C	0.0111	15.42	7.52	13.1	11.54
D	0.0051	20.95	4.56	5.6	6.84
E	0.0025	21.86	1.98	3.7	5.20
F	?	46.69	?	21.1	54.06

* Calculated on assumption that particles are spheres with a specific gravity of 2.6.

TABLE 3

Base exchange capacity of soil fractions

(Average of Wabash, Cherokee, Derby, and Summitt soils)

SOIL FRACTION*	BASE EXCHANGE CAPACITY PER 100 GM.	BASE EXCHANGE CAPACITY PER 100,000 SQ. CM. SURFACE	FRACTION, PER CENT OF SEPARATE	FRACTION BASE EXCHANGE CAPACITY, PER CENT OF SEPARATE BASE EXCHANGE CAPACITY
	m.e.	*m.e.*		
A 2.0–2.4	19.5	49.44	9.6	41.5
A 2.4–2.6	4.1	10.66	45.8	41.7
A 2.6–	1.7	4.42	44.7	16.8
B 2.0–2.4	20.1	23.72	9.4	34.6
B 2.4–2.6	5.3	6.25	43.3	42.0
B 2.6–	2.5	2.95	47.3	23.4
C 2.0–2.4	25.0	11.93	20.8	47.7
C 2.4–2.6	13.1	6.25	27.5	33.0
C 2.6–	4.1	1.96	51.5	19.3
D 2.0–2.4	20.5	4.51	43.8	57.3
D 2.4–2.6	12.7	2.79	45.5	36.9
D 2.6–	8.7	1.91	10.5	5.8

* The E and F separates were not fractionated. Because of their small size and tendency to absorb air etc., no satisfactory way to separate the individual particles according to specific gravity has been devised. A definite trend in the A, B, C, and D separates is evident.

weight regardless of the degree of fineness. The base exchange capacity of the 2.4–2.6 and 2.6–+ fractions increased as the degree of fineness increased. All

fractions showed decrease in base exchange capacity per unit area as the size of the particles decreased.

These data tend to indicate that there are at least two minerals present in the soil studied which are active in base exchange phenomena and that they differ somewhat in their base exchange characteristics.

Of the four soils studied the two fertile soils contained a much larger percentage of light minerals than did the unfertile soils. This is considered a separate problem, and additional soils are being investigated before publication.

Recently two articles have appeared in the literature dealing with the general problem presented in this paper. Hissink, Hooghoudt, and van der Spek (2) relate particle size of soils with soil properties, and Elder and McCall (1) associate specific gravity of soil particles with soil classification.

CONCLUSIONS

On a basis of the four soils studied the following points appear to have been established:

As particle size in soil separates decreases, base exchange capacity increases per unit weight but decreases per surface area.

As particle size in soil fractions decreases, base exchange capacity of the 2.0–2.4 fraction remains constant but that of the 2.4–2.6 and 2.6–+ fractions increases per unit weight.

All soil fractions as they become finer exhibit smaller base exchange capacity per unit surface area.

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MANGANESE IN NEW JERSEY SOILS[1]

A. W. BLAIR AND A. L. PRINCE[2]

New Jersey Agricultural Experiment Station

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Years of careful study and investigation have led plant physiologists to the definite conclusion that manganese is one of the elements essential for plant growth. The literature on this subject is extensive and has been so fully reviewed that only a few references need be given here (2, 3, 4, 5, 8, 9). Careful experimental work has also shown that normal soils which are slightly to moderately acid usually contain sufficient manganese for normal plant growth. This manganese may or may not be in an available form, depending upon the soil reaction. For example, heavy liming may convert the soluble manganese into an insoluble or slowly soluble form, in which case there may be an actual manganese deficiency as far as the growing plant is concerned. This condition has been observed in the case of overlimed lettuce and spinach soils. Generally such a condition can be improved by applying a soluble manganese salt, as, for example, manganese sulfate, or by reducing the pH of the soil to a point where more manganese may be brought into solution. It rarely happens that manganese is present to such an extent as to prove toxic.

In view of the widespread interest in this subject, it has seemed worth while to make a survey of the manganese in the soils of New Jersey. To that end, samples of soil representing the most important types found in the state have been analyzed for manganese.[3]

In some cases a considerable number of soil samples have been collected from areas where the soils do not differ very much as to type, as for example Sassafras loams and sandy loams. In such cases it has seemed sufficient to report the average manganese content, with the maximum and minimum, rather than to report each individual sample. This plan has been followed with samples collected from the important potato areas of Middlesex and Monmouth Counties, largely loams and sandy loams; with similar samples collected from farms in the vicinity of Plainsboro where dairying is important and from a dairy farm at Juliustown; and with a few samples of loams and silt loams from dairy farms in Somerset County. In addition, manganese has been determined in samples

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of soil chemistry and bacteriology.

[2] The authors are indebted to Mr. Patrick Martin, E. R. A. chemist, assigned to the soil department, for the major portion of the manganese determinations on the soil samples.

[3] For the determinations of manganese in soils from the Sussex area, New Jersey, see (1). Robinson also has determined manganese in some important American soils (6, 7).

TABLE 1

Manganese content of various soils

	MnO IN UNCULTIVATED SOILS	MnO IN CULTIVATED SOILS
	per cent	*per cent*
Loams and sandy loams from farms in the vicinity of Plainsboro. Average of 23 samples (maximum 0.084, minimum 0.019)	.....	0.055
Sandy loams from Juliustown. Average of 5 samples (maximum 0.019, minimum 0.013)	.....	0.016
Loams and sandy loams from potato areas of Middlesex County. Average of 19 farms	0.034	0.039
Loams and sandy loams from potato areas of Monmouth County. Average of 21 farms	0.035	0.035
Loams and silt loams from Somerset County. Average of 6 farms	0.095	0.093
Blueberry soils from Cranbury Substation, Burlington County:		
Average of plots A, B, C	.....	0.013
Average of plots H to N	.....	0.007
Virgin soil	.....	0.006

Belvidere Area

SOIL NUMBER		MnO IN CULTIVATED SOILS
		per cent
480	Washington loam	0.232
484	Chester gravelly loam	0.142
496	Dutchess loam	0.084
500	Dover loam	0.116

Bernardsville Area

640	Dunellen loam	0.116
650	Merrimac loam	0.131
658	Merrimac sandy loam	0.052
662	Gloucester loam	0.065
666	Clyde silt loam	0.013
678	Montalto loam	0.129
682	Croton silt loam	0.032
684	Whippany loam	0.032
704	Penn gravelly loam	0.258
718	Penn gravelly silt loam	0.194
728	Penn silt loam	0.071
714	Hagerstown silt loam	0.168
700	Chester loam	0.155
720	Washington loam	0.207

Camden Area

326	Sassafras loamy sand	0.019
338	Sassafras sandy loam	0.019

TABLE 1—*Concluded*

SOIL NUMBER		MnO IN CULTIVATED SOILS
	Camden Area—Concluded	
		per cent
360	Sassafras sand	0.019
397	Collington loam	0.039
416	Collington sandy loam	0.019
422	Collington sand	0.019
455	Keansburg loam	0.013
	Chatsworth Area	
735	Lakewood sand	0.013
749	Collington sand	0.019
751	Collington fine sandy loam	0.019
794	St. John's sand	0.019
	Freehold Area	
227	Sassafras loam	0.052
239	Sassafras sand	0.013
264	Sassafras fine sand	0.013
272	Sassafras fine sandy loam	0.019
284	Collington sand	0.013
315	Collington sandy loam	0.013
295	Colts Neck loam	0.039
233	Colts neck sandy loam	0.026
308	Keyport loam	0.019
	Millville Area	
636	Sassafras sand	0.013
526	Sassafras sandy loam	0.039
536	Lakewood sand	0.013
610	Norfolk sand	0.013

representing a number of soil types in six of the ten soil areas of the state. This gives a fair evaluation of the manganese content of the more important soil types found in the state. It is of interest to note that the soils of north Jersey, especially the loams, silt loams, and shale loams, generally contain a higher percentage of manganese than do the lighter soils of south Jersey. This is due in part at least to the manner of formation, the soils of south Jersey being predominantly coastal plain soils of marine origin, whereas those of north Jersey are predominantly residual, glaciated, and alluvial and therefore retain more of the manganese that was in the original rocks. The Lakewood, Collington, and Colts Neck sands generally show a low percentage of manganese.

Manganese has been determined in a large number of soils as indicated in table 1.

The manganese content of Penn shale loam which has been under definite fertilizer treatment for a period of years is reported in table 2. This soil is rather high in manganese, about twice as high as is Sassafras loam. If a very small fraction of this total could become available each year, it would undoubtedly supply the needs of most growing plants. Fertilizer and lime treatments do not appear to have had a definite influence on the percentage of manganese in the soil.

TABLE 2

Manganese in Penn shale loam—1932 samples

(Continuous fertilizer treatment since 1898)

CYLINDER NUMBER	FERTILIZER TREATMENT	MnO IN SOIL
		per cent
8A	Complete fertilizer, nitrogen as $NaNO_3$. Unlimed	0.129
8B	Complete fertilizer, nitrogen as $NaNO_3$. Limed	0.114
8C	Complete fertilizer, nitrogen as $NaNO_3$. Limed	0.103
17A	Complete fertilizer, nitrogen as $(NH_4)_2SO_4$. Unlimed	0.103
17B	Complete fertilizer, nitrogen as $(NH_4)_2SO_4$. Limed	0.119
17C	Complete fertilizer, nitrogen as $(NH_4)_2SO_4$. Limed	0.129

TABLE 3

Percentage of manganese (MnO) in horizon samples from field plots (1934 samples)*

HORIZON	UNLIMED SECTION							LIMED SECTION						
	Plot 2A	Plot 3A	Plot 7A	Plot 9A	Plot 10A	Plot 11A	Plot 18A	Plot 2B	Plot 3B	Plot 7B	Plot 9B	Plot 10B	Plot 11B	Plot 18B
A_p	0.065	0.064	0.039	0.039	0.019	0.026	0.026	0.023	0.019	0.019	0.019	0.019	0.016	0.032
A_2	0.045	0.071	0.019	0.039	.....	0.039	0.026	0.019	0.013	.....	0.019	0.019	0.013	0.019
B_1	0.019	0.032	0.019	0.026	0.019	0.039	0.019	0.019	0.013	0.019	0.019	0.019	0.013	0.019
B_2	0.019	0.019	0.019	0.019	0.019	0.026	0.019	0.013	0.013	0.013	0.019	0.013	0.013	0.019
C	0.013	0.013	0.013	0.013	0.013	.....	.....	.....	0.013	0.013	.....	0.013	0.013	0.013

* Fertilizer treatment:

2A and 2B—Muriate of potash, 160 lbs. to acre.
3A and 3B—Superphosphate, 320 lbs. to acre.
7A and 7B—Nothing.
9A and 9B—Complete fertilizer (N as $NaNO_3$).
10A and 10B—Complete fertilizer (N as $Ca(NO_3)_2$).
11A and 11B—Complete fertilizer (N as $(NH_4)_2SO_4$).
18A and 18B—Complete fertilizer and manure (N as $NaNO_3$).

Table 3 shows the manganese content of profile samples from certain of the soil fertility plots where the fertilizer treatment has been varied over a period of 27 years. A study of the table does not indicate any definite relationship between the percentage of manganese in the soil and the fertilizer treatment. For example, plot 9A, which receives a complete fertilizer but no manure, shows slightly more manganese than plot 18A, which receives the complete fertilizer

plus 16 tons of manure annually. Since manure contains some manganese the soil from plot 18A might be expected to contain more manganese than that from plot 9A. It is probable that the amount of manganese in the manure used is too small to effect sufficient change in the soil to be detected by a chemical analysis.

Attention may be directed to the fact that in the majority of cases manganese is lower in the limed than in the unlimed soils. It is possible that this may be

TABLE 4

Crop yield, manganese in the soil and in the crop

(Sassafras loam with variations in lime treatment)

PLOT NUMBER	LIME TREATMENT (ACRE BASIS)	pH OF SOIL*	YIELD OF HAY		MnO IN THE CROP		MnO IN SOIL
			Alfalfa—1933				
			Second cutting	Third cutting	Second cutting	Third cutting	
			lbs. per acre	*lbs. per acre*	*per cent*	*per cent*	*per cent*
28	No lime	4.6	52	575	0.018	0.096	0.052
29	1000 lbs. Ca limestone	5.1	434	1138	0.020	0.055	0.052
30	2000 lbs. Ca limestone	5.3	1525	2120	0.018	0.025	0.036
31	4000 lbs. Ca limestone	5.8	2176	2150	0.009	0.022	0.046
			Mixed grasses—1935 and 1936				
			1935	1936	1935	1936	
35	No lime	4.9	2100	984	0.064	0.090	0.044
36	1000 lbs. Ca limestone	5.2	2588	1253	0.098	0.072	0.041
37	2000 lbs. Ca limestone	5.5	3290	1909	0.046	0.042	0.041
38	4000 lbs. Ca limestone	6.4	3924	2660	0.033	0.027	0.036
			Wheat—1935				
			Grain	Straw	Grain	Straw	
E	No lime	4.8	2347	3345	0.007	0.017	0.058
F	1000 lbs. Ca limestone	5.1	2828	4455	0.006	0.016	0.071
G	2000 lbs. Ca limestone	5.3	2876	4396	0.004	0.004	0.058
H	4000 lbs. Ca limestone	6.4	3228	4828	0.003	0.003	0.058

* Determined for alfalfa and wheat plots in 1934 and for mixed grass plots in 1936.

due to the fact that in most cases larger crops have been taken from the limed than from the unlimed plots and therefore more manganese has been removed. In certain other cases, however, liming has not made a significant difference in the manganese content of the soil.

With slight exception the A_p horizon contains more manganese than the A_2 or the B_1 horizon. From B_1 to C the difference is generally slight. The higher percentage of manganese in the A_p horizon may be due in part to the higher content of organic matter in this horizon.

Table 4 reports results obtained on samples from experimental plots which have been, for a long time, under different treatments with respect to lime. In this case the lime treatment, the pH, the crop yield, and percentage of manganese in the crop are given, as well as the percentage of manganese in the soil. The figures do not show a definite relationship between the lime treatment of the soil and the percentage of manganese in the soil. There is, however, a very interesting relationship between the lime treatment and the percentage of manganese in the *crop*. With slight exception, the percentage of manganese in the crop is highest with no lime, and decreases with the increase in the amount of lime applied. The explanation is no doubt to be found in the fact that heavy liming would tend to convert the soluble manganese into a less available form, and it is quite probable that under such conditions plants would absorb less manganese than they would if grown in a more acid soil. The fact that the crop yield has increased with increase in the amount of lime applied may possibly be taken as an indication that the yield has not been affected by the lowered intake of manganese. Further work will be done along this line.

SUMMARY

Manganese has been determined in soils representing the more important types found in New Jersey.

In general, the percentage of manganese is higher in soils from the northern part of the state than in those from the southern part, that is, those south of the line connecting New Brunswick and Trenton. The manner in which the soils of the two sections of the state have been formed undoubtedly has something to do with the difference in manganese content.

Long-time manure, fertilizer, and lime treatments do not appear to have influenced the manganese content of the soil. In soils from certain of the experimental plots a rather distinct difference was found between the manganese content of the surface soil, that is the A_p horizon, and the A_2 and B horizons, the amount generally decreasing from the A_p to the B_1 horizon.

Manganese was also determined in certain crop samples from plots that have received no lime and also from plots that have been moderately and heavily limed. With slight exception, the manganese content of the crop decreased with increase in the amount of lime applied. In explanation of this, it is suggested that with heavy liming the manganese is rendered less available, and therefore the crop takes up less of this element. The lowered intake of manganese by the plant does not appear to have a deleterious effect with reference to yield.

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THE INFLUENCE OF CERTAIN REPLACEABLE BASES IN THE SOIL UPON THE ELEMENTAL COMPOSITION OF VEGETABLE CROPS

JACKSON B. HESTER AND FLORENCE A. SHELTON

Virginia Truck Experiment Station

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A review of the literature reveals that the elemental composition of plant material influences the well-being of animal life. A further study shows that several factors—soil type (1, 5, 6, 13, 14), plant species (11, 13, 15), climatic conditions (2, 3, 4, 9), age of plant (11), and others (1; 10; 12, p. 232–307; 16) —influence the composition of plant material. This paper deals with the effect of certain replaceable bases in the soil upon the elemental composition of some vegetable crops grown under controlled conditions.

EXPERIMENTAL PROCEDURE

Three distinctly different virgin soil types, a Portsmouth loamy fine sand (13.50 per cent organic matter and 274 m.e. exchange capacity per thousand grams of soil), a Bladen sandy loam (1.76 per cent organic matter and 102 m.e. exchange capacity), and a Norfolk fine sand (1.00 per cent organic matter and 48 m.e. exchange capacity) were brought to the greenhouse, screened, and placed in 2-gallon "coffee urn lining" pots. The soils were treated with various bases, and several crops were grown in them before the crops here mentioned were planted. These data have been given in various other publications (7, 8). This phase of the subject will not be discussed, since this paper deals only with some of the soil factors that influence the elemental composition of the plant material. It is sufficient to mention that in addition to the treatment shown in the tables, the pots were all fertilized with a basic application of nitrogen, phosphorus, and potash. These materials were given in several applications as the plants increased in size. Five plants in each case were grown in each pot, and the figures given are for two or more closely agreeing pots. The analyses for the nutrients leached were obtained from 1500 cc., or the equivalent of about 2 inches of rain water leached through the soil at the end of the growing season. The soils were then sampled and the replaceable bases determined. These results together with the analyses of the plants are given in table 1.

COMPOSITION OF PLANT MATERIAL

Plants exhibit certain selective powers for absorbing nutrients (12, p. 232–307) but are greatly influenced by the composition of the soil solution. While

TABLE 1

The influence of soil type and calcium lime upon the composition of the lima bean plant

pH of soil	Per cent base saturation pH 7.0	Free $CaCO_3$	Replaceable*			Leached†				Dry weight, grams		M.E. per gram dry matter									
		M.e. per 1000 gm. soil	M.e. per 1000 gm. soil			M.e. per 1000 gm. soil						Vegetation					Pods				
			Ca	Mg	K	Ca	Mg	K	N	Tops	Pods	Ca	Mg	K	N	P	Ca	Mg	K	N	P
Portsmouth Soil																					
4.0	10	....	27	11.2	15.4	2.00	0.62	1.37	6.48	9.1	5.3	0.36	0.30	1.41	2.82	0.43	0.10	0.17	0.70	2.56	0.23
5.1	41	....	114	13.4	7.4	0.32	0.73	0.08	0.37	26.5	43.5	1.56	0.32	0.56	1.10	0.38	0.10	0.15	0.48	1.58	0.16
6.1	74	6	202	9.9	6.5	0.55	0.34	0.06	0.09	36.4	52.5	2.00	0.20	0.34	1.04	0.29	0.16	0.20	0.63	1.60	0.28
6.8	97	18	267	11.7	8.8	0.53	0.12	0.08	0.05	36.6	47.1	2.06	0.20	0.41	1.04	0.28	0.18	0.24	0.61	1.76	0.30
7.0	107	28	294	11.7	8.3	0.96	0.13	0.29	0.09	36.8	45.7	2.48	0.19	0.48	1.24	0.26	0.20	0.24	0.63	1.86	0.30
Bladen Soil																					
4.0	15	....	16	10.8	16.2	3.22	0.75	1.93	5.22	....	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5.6	47	....	48	15.9	6.1	0.65	0.15	0.05	0.07	29.2	49.7	2.04	0.45	0.41	1.14	0.30	0.02	0.38	0.61	1.70	0.34
6.6	80	8	81	14.2	6.0	0.78	0.14	0.05	0.02	33.7	51.3	2.26	0.34	0.34	1.10	0.27	0.08	0.36	0.59	1.74	0.34
7.2	123	44	126	15.9	4.9	0.53	0.20	0.04	0.04	41.8	49.7	2.22	0.34	0.20	1.20	0.27	0.20	0.29	0.59	1.84	0.32
Norfolk Soil																					
5.0	28	....	13	9.8	3.9	1.72	0.40	0.96	0.92	27.9	32.0	0.46	0.28	1.07	1.96	0.36	0.08	0.24	0.71	2.24	0.30
5.5	37	....	18	15.0	3.8	1.08	0.37	0.29	0.14	29.5	38.8	0.88	0.55	0.65	1.30	0.44	0.04	0.35	0.68	1.78	0.35
5.7	48	....	23	14.7	4.1	0.84	0.38	0.15	0.08	30.7	44.7	1.02	0.75	0.51	1.06	0.38	0.18	0.30	0.61	1.66	0.32
6.1	81	....	39	11.0	4.3	1.54	0.32	0.10	0.08	35.3	42.4	1.36	0.48	0.43	0.92	0.38	0.18	0.27	0.65	1.86	0.32
7.0	118	40	57	9.2	4.5	2.14	0.17	0.14	0.08	48.1	41.6	1.54	0.31	0.43	0.72	0.31	0.22	0.26	0.66	1.54	0.30

* Determined by leaching 25 gm. of soil with 500 cc. of 0.5 *N* ammonium chloride (after crop grown).

† Determined on leaching at the end of cropping period (1500 cc. per pot).

TABLE 2

The influence of different bases upon the composition of the lima bean plant in Portsmouth soil

	pH of soil	Per cent base saturation pH 7.0	Free $CaCO_3$	Replaceable*			Leached†				Dry weight, grams		M.e. per gram dry matter									
													Vegetation					Pods				
			M.e. per 1000 gm. soil	M.e. per 1000 gm. soil			M.e. per 1000 gm. soil															
				Ca	Mg	K	Ca	Mg	K	N	Tops	Pods	Ca	Mg	K	N	P	Ca	Mg	K	N	P
	4.0	10	....	27	11.2	15.4	2.00	0.62	1.37	6.48	9.1	5.3	0.36	0.30	1.41	2.82	0.43	0.10	0.17	0.70	2.56	0.23
High calcium	6.1	74	6	202	9.9	6.5	0.55	0.34	0.06	0.09	36.4	52.5	2.00	0.20	0.34	1.04	0.29	0.16	0.20	0.63	1.60	0.28
High magnesium	6.1		4	68	70.6	7.3	0.30	0.17	0.04	0.23	35.6	45.4	0.94	1.36	0.44	1.22	0.29	0.14	0.42	0.66	1.82	0.36
Calcium and magnesium	6.0		....	124	56.2	6.2	0.20	0.15	0.08	0.07	35.6	43.9	1.62	0.61	0.44	1.28	0.27	0.18	0.37	0.63	1.98	0.33
High potassium	5.6		....	93	12.6	33.0	0.57	0.11	1.44	0.09	41.9	45.6	0.92	0.17	1.36	1.36	0.25	0.10	0.14	0.87	2.04	0.19
Calcium, magnesium, and potassium	5.9		....	116	54.5	15.2	0.39	0.16	0.21	0.02	40.6	42.9	1.02	0.63	0.54	1.02	0.32	0.12	0.34	0.70	1.56	0.30

* Determined by leaching 25 gm. of soil with 500 cc. of 0.5 *N* ammonium chloride (after crop grown).

† Determined by leaching at the end of cropping period (1500 cc. per pot).

the replaceable calcium in the Portsmouth soil varied from 27 to 294 m.e. per thousand grams of soil, the vegetative material grown on this soil varied from 0.36 to 2.48 m.e. The calcium leached was greater for the no-calcium treated pots than for the high-calcium treatment. This indicates that there was not an actual calcium shortage in the no-calcium treated pots but that other interfering factors limited its absorption. Unabsorbed (plant) anions (nitrates, chlorides, sulfates, etc.) largely account for the leaching of replaceable bases. Although the replaceable potassium and magnesium were about the same in each of the pots (table 1) at the beginning of the experiment, the greater absorption by the larger plant growth on the limed soils somewhat changed that found

TABLE 3

The influence of different bases upon the composition of collards

	pH of soil	Leached m.e. per 1000 gm. soil				Dry weight, grams	m.e. per gram dry matter				
		Ca	Mg	K	N		Ca	Mg	K	N	P
Portsmouth Soil											
High calcium	4.0	2.91	0.93	1.47	5.95	3.1	0.38	0.22	1.13	3.30	0.53
	6.0	0.51	0.21	0.04	0.14	35.6	1.48	0.19	0.97	1.68	0.45
High magnesium	6.4	0.51	0.35	0.02	0.74	35.4	1.00	0.66	1.22	2.06	0.61
High potassium	5.6	0.56	0.51	0.41	0.08	34.4	1.10	0.27	2.27	2.38	0.50
Calcium and magnesium	6.5	0.37	0.17	0.02	0.06	40.2	1.16	0.62	0.90	1.88	0.45
Calcium, magnesium, and potassium	6.6	0.54	0.22	0.09	0.14	38.5	0.74	0.43	1.10	1.42	0.43
Bladen Soil											
	4.3	4.07	1.11	1.37	4.78	1.8	0.86	0.32	1.71	4.34	0.38
	5.6	0.76	0.12	0.06	0.14	37.4	1.00	0.27	1.06	1.12	0.49
Norfolk Soil											
	5.3	1.75	0.42	2.10	4.54	1.6	0.69	0.27	1.59	3.66	0.58
	5.9	0.55	0.16	0.02	0.00	32.5	0.92	0.43	1.04	1.36	0.52

after the harvest of the crops. The magnesium content of the plant material varied somewhat on the different calcium treated soils but not as greatly as did the potash and nitrogen. The pods showed a lesser variation for all of the elements, as has been previously reported in the literature.

The analyses of the plant material from the Bladen and Norfolk soils are similar to those of the Portsmouth soil but are less pronounced. This is perhaps due to the lesser variation in the amounts of replaceable lime required to bring the soils to a neutral reaction. Consequently, there was a lower ratio of calcium to the other bases in these two soils. One noticeable difference was in the low calcium content of the pods at the low pH values.

INFLUENCE OF CERTAIN BASES UPON ABSORPTION OF OTHER PLANT NUTRIENTS

In the original soil treatment of the Portsmouth series, a part of the calcium carbonate was replaced with magnesium and potassium carbonate in changing the soil reaction to a condition more favorable for plant growth; and the influence of the added element upon the composition of the plant was determined. These data, given in table 2, support the data in table 1 in showing that a particular base in the soil greatly influences the absorption of the plant nutrients. For example, a high replaceable calcium content in the soil suppresses the absorption of potassium, nitrogen, and magnesium by the plant; a high replaceable magnesium content suppresses the absorption of potassium, calcium, and nitrogen; and a high potassium content suppresses the absorption of calcium, magnesium, and nitrogen.

COMPOSITION OF COLLARDS

Collards were grown on the variously treated soils and were harvested at maturity or at about the time they would have been cut for consumption. The chemical analyses of certain plant materials are given in table 3. From these analyses it is learned that even though the yields were not greatly influenced by a certain treatment, such as high magnesium or high calcium, the elemental content of the added mineral was greatly increased at the expense of the absorption of other elements.

SUMMARY

The presence of a large amount of a particular replaceable base in the soil colloidal complex influenced the elemental composition of plant material even though the yields were affected but little. A high replaceable calcium content suppressed the absorption of potassium, nitrogen, and magnesium; a high replaceable magnesium content suppressed the absorption of potassium, calcium, and nitrogen; and a high potassium content suppressed the absorption of calcium, magnesium, and nitrogen.

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OXYGEN AND CARBON DIOXIDE CONTENT OF CULTURE SOLUTIONS IN RELATION TO CATION AND ANION NITROGEN ABSORPTION BY TOMATO PLANTS[1]

L. B. ARRINGTON AND J. W. SHIVE

New Jersey Agricultural Experiment Station

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The necessity of adequate soil aeration for the normal healthy root development of most species of mesophytic plants has for some time been considered as due largely to the favorable supply of oxygen which is thus furnished by the soil atmosphere. Since the percentage volume of soil air to be found at any given time or place is variable, being dependent chiefly upon the physical nature of the soil, the size of its particles, and especially its water content, the supply of oxygen may thus become a limiting factor in the growth and development of roots under certain conditions.

Furthermore, as Cannon (5, 6) has shown, different species growing under the same conditions may vary appreciably as to their oxygen requirements for root growth; and the requirements of any given species may in turn vary according to the temperature of the root medium.

In the case of solution cultures, the problem of maintaining a favorable oxygen supply in the culture medium becomes of even greater importance than under soil conditions, since the roots of large, rapidly growing plants are apt to extract oxygen from the solution more rapidly than it can be absorbed by the solution from the atmosphere. To offset this condition of oxygen deficiency, artificial aeration of culture solutions has been employed in various instances, usually with marked success.

Sachs (16), in his pioneer work with nutrient solutions as early as 1860, encountered this problem with some of his cultures, notably those whose roots completely filled the culture jars, and these he aerated with beneficial results. Since then, others in increasing numbers have repeatedly demonstrated the desirability of aerating culture solutions when employed in experimental studies with plants.

Arker (4), in 1901, reported that growth of lupine roots was more rapid, in both soil and water cultures, when a stream of air was passed through the culture medium than it was without artificial aeration. Using the same species and also barley, Hall, Brenchley, and Underwood (11) later obtained a 50 per cent increase in total dry weight of plants grown with aeration over those grown without.

Allison and Shive (1) made a thorough study of the effect of aeration on the

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growth of soybean plants in sand and water cultures, with and without continuous renewal of solution. They obtained greater growth of both roots and tops with aeration than without, in the cultures with continuous solution renewal; but with only periodic renewal of solution, the aeration benefited the root growth of the plants, but not appreciably the top growth. More recently Clark and Shive (7) have obtained beneficial results of aeration with tomato plants, using the constant drip method of continuous solution renewal.

In a very significant and important study recently reported, Loehwing (14) states that continuous soil aeration with moist air increased size and growth rates of plants, but very rapid aeration had the opposite effect. This indicates the possibility of setting up, under certain conditions, excessive soil oxygen tensions which might tend to inhibit rather than to promote plant growth.

While the influence of oxygen has generally been regarded as of paramount importance in the relationship of aeration of culture media to root growth, the possibility has been suggested by some authors that the carbon dioxide content of the solution may also be involved in this relationship. When the high solubility of this gas in an aqueous medium and the relatively high rate of respiration of the roots of vigorously growing plants are considered, it is not surprising that the quantity of carbon dioxide present in culture solutions is frequently found to be far in excess of that normally present in the atmosphere.

There is evidence to show that relatively high concentrations of carbon dioxide, such as may be found in culture solutions, may be decidedly injurious to plant growth. It has been shown by Free (10) that bubbling carbon dioxide through culture solutions containing buckwheat plants produced injury in several hours and caused the death of the plants in a few days, whereas the same treatment with air, oxygen, or nitrogen produced no injurious effects. Knight (13), using the same treatment with corn plants in solution cultures, found a better correlation of the rate of root growth of the plants with the carbon dioxide content of the solutions, in an inverse ratio, than with the oxygen content in a positive ratio. From this he concluded that carbon dioxide and not oxygen was the limiting factor in the growth of the roots in his experiments.

It is quite possible that the aerating treatment such as was used in the present experiment might influence the carbon dioxide content of the solution by sweeping out some of the dissolved gas along with the air bubbles constantly passing through the solution. Accordingly, in connection with this study dealing with the relation between cation and anion nitrogen absorption by the tomato plant and the oxygen level of the culture solutions, a study was also made of the effect of the carbon dioxide content of the solution on the rates of nitrogen absorption under consideration and on growth yields, in order to determine whether or not this factor might play a significant part in the relation between aeration and ion absorption.

EXPERIMENTAL METHODS

Tomato plants of the variety Marglobe were grown in solution cultures for all the experimental work here described. The plants were obtained from seed

of a selected strain, which produced individuals having a reasonable degree of uniformity in both type of plant and vigor of growth.

Solution

The culture solution used throughout the growth period of the plants, as well as during the experimental test intervals, was one of the Tottingham type, a modified four-salt solution of the ammonium sulfate series used and described by Jones and Shive (12). This solution had previously been found to give good growth of the tomato in water cultures; moreover, since it contained approximately equivalent concentrations of nitrogen as ammonium and as nitrate, it was well suited for use in testing the comparative rates of absorption of these two forms of nitrogen by the plants.

The solution was first used at a concentration of 0.1 atmosphere for the very young plants, and the concentration was increased successively to 0.5 and then to 1.0 atmosphere, as the plants increased in size. The pH of the solution was adjusted by the use of normal potassium hydroxide and sulfuric acid, the purpose of which will be stated. The various constituents and the quantities of each of the salts which were used in making up the solution, at the different concentrations are given in table 1.

TABLE 1

Milliliters of half-molar stock solutions, used in making up 1 liter of culture solution at three concentrations

STOCK SOLUTIONS	0.1 ATM.	0.5 ATM.	1.0 ATM.
KH_2PO_4	0.42	2.12	4.23
$MgSO_4$	1.42	7.12	14.23
$(NH_4)_2SO_4$	0.56	2.80	5.60
$Ca(NO_3)_2$	0.58	2.92	5.84

Boron and manganese, in quantities of 0.5 p.p.m. each, were supplied to the plants in all series, in the form of boric acid and of manganese sulfate, respectively. Iron, in the form of ferrous sulfate, in solution made up fresh at every application was supplied at the rate of 0.5 to 3 p.p.m. of iron, according to the needs of the plants.

Growing the plants

Seeds were germinated in shallow boxes of clean washed white sand and grown there for from one to two weeks after germination. During this period the young plants received frequent applications of the culture solution, sprinkled on the surface of the sand, at a concentration 0.1 atmosphere and at pH 5.3.

When the seedlings were about 4 cm. high, the most uniform individuals were selected and transferred from the sand to culture solutions in 2-quart fruit jars of colorless glass, three plants to a jar. These were supported at the

top of the jar, after the method used and described by Tottingham (20). The plants in all cases remained in these supports to the completion of the experiments.

After the plants had grown to considerable size, they were transferred together with their supports from the 2-quart containers to 4-quart containers. This allowed for a greater volume of solution in continual contact with the roots and also provided more room for the rapidly growing root systems.

When the young plants were first transferred from sand to the culture jars the solutions were renewed at sufficiently frequent intervals to prevent any marked change in pH until the plants had attained a height of about 15 cm. During this preliminary growth period, the solution of each culture was kept as nearly as possible at pH 5.3, but the total concentration of the solution was gradually increased from 0.5 atmosphere to 1.0 atmosphere.

At this time the technique for the main part of the experimental period was instituted and it was maintained to the end of the experiments, when the plants were tested and then harvested. This technique included (*a*) the continuous flow according to the method described by Shive and Stahl (18), (*b*) use of the solution at two different pH levels (one group of plants at pH 4 and the other group at pH 7), and (*c*) artificial aeration of each individual culture. At first each culture received the solution at the rate of 1 liter in 24 hours, and later at double the rate.

The purpose of growing and testing these plants at the two different pH levels may be briefly explained by referring to the work of Clark and Shive (8), who showed that the pH of the culture solution exerts a significant influence on the rates of absorption of ammonium and nitrate ions by the roots of plants. Thus, in the present work it was deemed essential to take into consideration this important factor.

The stimulating effect of artificial aeration of the culture solution on the growth made by vigorous plants of the type and species here used has also been well brought out by Clark and Shive (7). A more specific study of the nature of this influence on one factor concerned in the growth of plants, namely, the rates of absorption by the plants of the two forms of nitrogen from the culture solution, is the chief purpose, of course, of the present work, in the experiments about to be described.

Aeration of these cultures was effectively accomplished by the method previously used by Allison and Shive (1), but their apparatus was here modified for use on a much more extensive scale than was required for their purpose.

Air was admitted through a glass tube at the bottom of the culture jar as a jet of small bubbles passing up freely through the solution. The rate of bubble flow was regulated to deliver approximately 10 bubbles per second. The size of bubbles in the various cultures was fairly uniform, since the glass tubes were selected for uniformity of bore.

During the course of the experiments a comparison was made also between cultures which received continuous artificial aeration and those which received

none at all, with respect to the growth made and the general condition of the plants under the two treatments.

Testing the plants

When the plants had attained the desired size and the roots had completely filled the culture jars in which they were growing, tests were conducted. Each culture of the series was tested twice, with an interval of two days between the tests. The first of these tests aimed to determine the amount of oxygen and of carbon dioxide in solution, after an interval of 6 hours in contact with the plant roots under the several conditions of aeration and at the two levels of pH employed. The second test was then conducted with the same plants for the purpose of determining the rates of absorption of the nitrate and ammonium ions by the roots, under the same conditions of aeration and pH. All tests were carried out, using the same technique, during the 6-hour interval in the middle of the day and in bright sunlight. The cultures were arranged in the greenhouse to receive as nearly as possible uniform light and atmospheric conditions throughout the test period.

In each test, carried out in duplicate, four different groups of plants were involved as follows: (*a*) aerated at pH 4; (*b*) aerated at pH 7; (*c*) non-aerated at pH 4; and (*d*) non-aerated at pH 7.

Each culture of the four groups of plants was removed from the solution in which it had been growing, thoroughly washed by successive rinsings in five separate vessels of distilled water, and replaced in 3750 ml. of the test solution, accurately measured, in clean culture jars. This solution was identical in every respect with that in which the plants had previously been growing. Moreover, 500 ml. of fresh solution was flowed through each culture during the 6-hour test period by the method previously used and at the same rate as that employed prior to the test. Thus, 4250 ml. of test solution was used altogether.

Each culture was subjected to its respective treatment of aeration or non-aeration, as before described, as soon as it was placed in the test solution. In each test the cultures were started at intervals of from 10 to 12 minutes, in order to allow sufficient time for uniform treatment at the end of the test. This treatment consisted in collecting, for oxygen and carbon dioxide analyses, samples of the solutions from each of the culture jars at the end of the 6-hour test interval.

All test solutions used throughout the experiments were made up and exposed to the atmosphere for several days prior to their use, in order that they might come into equilibrium with the atmosphere, thus insuring as far as possible at the beginning of the test the same quantity of oxygen and of carbon dioxide in the solutions of all of the cultures. Duplicate samples of the solutions were taken just prior to each test, in order to determine the quantity of oxygen and of ammonium and nitrate nitrogen in the solution before it was exposed to the roots of the plants.

At the end of this first test period, each culture, after being sampled, was

restored to its former status for a period of two days, when the second test was begun.

The treatment of the cultures after the test period for absorption consisted in thoroughly washing the test solution from the roots of the plants in each culture with a fine stream of distilled water directed for a wash bottle, and in rinsing all glassware which had been in contact with the solution. Then, all solution and rinsings from each individual culture were collected in vessels large enough to allow for making up the solution to desired volume. Before being made up to volume, however, the solutions were first filtered through Whatman No. 4 filter paper, to remove any solid particles of organic matter which might alter the nitrogenous content of the solutions in the interim before the analyses could be made.

The plants of each culture were harvested directly after the absorption test was completed, and the green and dry weights of both stems and leaves were separately determined.

ANALYSES OF THE TEST SOLUTIONS

Oxygen

To determine the oxygen content of the samples of solution which were collected at the end of the 6-hour test periods, use was made of the Micro-Winkler method for determining dissolved oxygen, as proposed by Lund (15) with modifications as required. Further details of this procedure may be found in any standard work on volumetric analyses, such as that by Sutton (19).

Samples were collected directly from the culture jars in 50-ml. sample bottles, prepared according to the method used and described by Allison and Shive (2), by means of which the solution was transferred from the culture jar to the sample bottle without exposure to the atmosphere. With a few exceptions, all analyses herein recorded were run within a few minutes after sampling. In no case were the samples allowed to stand for any considerable period of time before analysis, and at all times they were carefully sealed from all contact with the atmosphere. Duplicate determinations were always made, and the oxygen content was calculated directly in terms of parts per million of oxygen.

Carbon dioxide

Samples of the test solution for carbon dioxide determinations were collected in 100-ml. sample bottles of the same type and in the same manner as for the oxygen analyses. The same necessity here of preventing exposure of the solution to the atmosphere as in the case of the oxygen samples is apparent. The method and the apparatus used in conducting the carbon dioxide analyses have been described in detail in another publication (4).

Ammonium and nitrate nitrogen

The method used for nitrogen analyses was a modification of the Folin aspiration method, worked out and described by Sessions and Shive (17). In-

stead of the sodium carbonate and sodium chloride used by them for the liberation of ammonia from the solutions, 5 ml. of 13 per cent sodium hydroxide per 100-ml. sample, as described by Clark (9), was here used, to bring the concentration of the sample slightly higher than 0.125 *N* NaOH. For nitrate recovery, Devarda's alloy, 2.5 gm. per 100-ml. sample, as used by Sessions and Shive, was added without the further addition of alkali.

EXPERIMENTAL RESULTS

The data here presented embody the results obtained with a series of plants, the cultures of which were started in September, grown during a period of 60 days and tested and harvested in November.

In this presentation direct comparison will always be made between the cultures which were aerated and those which were not aerated. Results of these two treatments will be compared separately for each of the two pH levels at which the plants were tested. Moreover, the consideration of the rates of absorption of nitrogen under the conditions of these treatments will always be taken up from two separate standpoints, (*a*) the absorption of ammonium (NH_4^+) ions and (*b*) the absorption of nitrate (NO_3^-) ions, for each of the four sets of conditions as just stated.

Oxygen content of solutions as influenced by contact with plant roots

The quantities of oxygen contained in these solutions before and after they had been in contact with the roots of the plants for the 6-hour test period, are presented in table 2. Since two separate stock supplies of solution were always prepared for these tests, one made up to pH 4.0 and the other to pH 7.0, the oxygen content before the tests was determined separately for each supply, after the solutions had been standing exposed to the atmosphere for a number of hours. The two values, averages of duplicate determinations, are here included. The oxygen content of all lots of solution thus determined before the tests showed agreement which was well within the limits of experimental error.

The most significant feature brought out in table 2 is the difference between the oxygen content of the solutions before and after the 6-hour test periods during which the plant roots were immersed in the solutions. Even under the influence of the continuous and vigorous aeration as here carried out, the oxygen content of the solutions expressed as the average for the cultures of like treatments at the end of the test period was only 14.9 per cent of the original content. The corresponding percentage value for the non-aerated cultures of the two series was very much less than that for the aerated, as might be expected, being only 3.6 per cent of the original oxygen content of the solutions.

This extreme depletion of the solutions of their available oxygen supply by vigorously growing plants in such a relatively short period of time is characteristic of all the non-aerated cultures tested in these experiments. The fact that the aerated cultures contained, in absolute amounts, less than 1 p.p.m. more of oxygen than the non-aerated, leads to the conclusion that even under the influence of the rapid aerating process here employed, the actual rate of

removal by the plants exceeds the solubility rate and is definite evidence of the pronounced deficiency in the available supply of this element in the non-aerated cultures. That such deficiency is directly correlated with retarded growth rates becomes clear from a consideration of yield values. In view of this fact it is reasonable to assume that any external factors which would significantly affect the supply of oxygen in the growth media would in turn have their corresponding effects on the vital processes of the roots. Of these factors, that of ionic absorption must necessarily be one of primary importance.

Without exception, the aerated cultures showed appreciably higher oxygen content than the corresponding non-aerated cultures.

TABLE 2

Oxygen content of solutions, before and after contact with plant roots during an experimental interval of 6 hours, at two pH levels

	ORIGINAL O_2 CONTENT	O_2 CONTENT AFTER CONTACT WITH PLANTS DURING 6-HOUR INTERVALS		RATIO AERATED / NON-AERATED
		Aerated	Non-aerated	
	*p.p.m.**	*p.p.m.**	*p.p.m.**	
pH 4.0	8.03	1.56	0.35	
		1.02	0.26	
	7.98	1.23	0.31	
		0.96	0.22	
Average	8.01	1.192	0.285	4.18
pH 7.0	7.95	2.20	0.37	
		1.87	0.46	
	8.11	0.62	0.56	
		0.55	0.39	
Average	8.03	1.310	0.445	2.94

*Or mgm. O_2 per l. of solution.

The exact numerical relationship between the average results of the two treatments, with and without aeration, may be represented as the ratio of the average value for the aerated to the corresponding value for the non-aerated cultures, as given in table 2. These ratio values show that the average oxygen content of the aerated cultures at pH 4.0 was 4.18 times that of the non-aerated cultures at the end of the 6-hour test period, whereas at pH 7.0 the average oxygen content of the aerated cultures was 2.94 times that on the non-aerated cultures.

The fact that the actual quantity of oxygen contained in any of the solutions at the end of a 6-hour interval, even under the influence of the aerating treatment, was relatively small with respect to the saturation point of the gas in solution under these conditions, does not alter the significance of the relationship just mentioned. Obviously these values, representing parts per million

of oxygen contained in solutions at the end of the 6-hour test period, give no indication of the total quantity of oxygen absorbed by the plants of any culture over the course of the 6-hour period. This of necessity follows from the nature of the experimental set-up, which does not permit a measurement or even an approximation of the actual quantity of oxygen dissolved by the solutions of either the aerated or the non-aerated cultures during the 6-hour test period, and hence the total oxygen taken from the solutions of the plant can not be estimated. It may reasonably be assumed, however, that the plants in the aerated cultures do absorb oxygen from solution at a higher rate than do the plants in the non-aerated cultures, since the roots of the former are continuously exposed to a higher oxygen potential than are those of the latter and since an enormously greater total volume of air is exposed to the solvent action of the aerated than to that of the non-aerated solution during this period.

Nitrogen absorption in relation to aeration

The numerical data relating to nitrogen absorption rates as influenced by aeration of the culture solutions are presented in table 3.

Comparison of the nitrogen absorption values for the aerated and non-aerated cultures shows a consistently higher rate of absorption of both ammonium and nitrate nitrogen per unit of plant tissue per unit of time from the aerated than from the corresponding non-aerated solutions. The importance of aeration as a factor influencing the nitrogen absorption rates here indicated is emphasized by the consistency with which this relationship holds at the two pH levels employed. Although there was an appreciable difference in the size of the plants at the two different pH levels, the plants of the aerated cultures at each pH level showed a higher absorption rate than did the plants of the corresponding non-aerated cultures.

The ratios of the average absorption rate values indicated for the aerated cultures to those indicated for the non-aerated cultures are given in the last two vertical columns of table 3. These ratios show that the average rate of absorption of NH_4—N from the aerated cultures at pH 4.0 was 2.29 times as high as the corresponding rate from the non-aerated cultures, and at pH 7.0 the rate was 1.34 times as high from the aerated cultures as it was from the non-aerated. The average NO_3—N absorption rate at pH 4.0 and at pH 7.0 is shown to be 1.31 and 1.30 times as high, respectively, from the aerated cultures as it is from the non-aerated.

Nitrogen absorption in relation to pH of the culture solutions

Consideration of the nitrogen absorption rates in relation to pH values very clearly brings out the fact that this solution factor itself exerted a very considerable influence on the actual rates of absorption of both the ammonium and the nitrate ions from the solution. In no instance, however, does this affect the general nature of the relationship between the aerated and the non-aerated treatments. The average rates of absorption were always higher in

the aerated than in the corresponding non-aerated cultures, regardless of the incidental effect of the pH of the culture solutions on corresponding absorption rates.

Thus, the ratios given in the last two horizontal lines of table 3 show that the actual average rate of absorption of NH_4—nitrogen from aerated solutions at pH 7.0 was 2.26 times as high as was the corresponding rate from the aerated solutions at pH 4.0, and from the non-aerated cultures at pH 7.0 the average rate of absorption of this ion was 3.85 times as high as it was from the corre-

TABLE 3

Ammonium and nitrate nitrogen absorbed during a 6-hour experimental interval from aerated and non-aerated culture solutions at two pH levels

	MGM. OF N PER 100 GM. GREEN TISSUE				RATIO OF ABSORPTION FROM CULTURES $\frac{\text{AERATED}}{\text{NON-AERATED}}$	
	NH_4—N		NO_3—N		NH_4—N	NO_3—N
	Aerated	Non-aerated	Aerated	Non-aerated		
pH 4.0	4.01	2.45	8.93	8.11		
	3.91	1.89	8.22	7.41		
	3.40	1.10	11.39	6.65		
	3.72	1.13	9.97	7.14		
Average	3.760	1.642	9.628	7.327	2.29	1.31
pH 7.0	10.21	7.64	9.79	5.21		
	9.09	5.99	5.42	5.72		
	8.60	5.51	5.53	3.55		
	6.04	6.18	2.03	3.01		
Average	8.485	6.330	5.692	4.372	1.34	1.30
Ratio of average absorption rates:						
$\frac{\text{pH 4.0}}{\text{pH 7.0}}$	0.443	0.259	1.69	1.68		
$\frac{\text{pH 7.0}}{\text{pH 4.0}}$	2.26	3.85	0.591	0.596		

sponding cultures at pH 4.0. On the other hand, the average absorption rate of the NO_3—nitrogen from the aerated solutions at pH 4.0 was 1.69 times as high as it was from the aerated cultures at pH 7.0, and from the non-aerated cultures at pH 4.0 the average rate was 1.68 times as high as it was from the corresponding cultures at pH 7.0. These results are in entire accord with the previous work of Clark and Shive (9).

Weight yields produced by aerated and non-aerated cultures

A comparison was made of the total plant growth produced by the cultures which were continuously aerated with that produced by the corresponding

non-aerated cultures, during the growth period of 60 days. The numerical data relating to the green and dry weight yields of the plants are presented in table 4.

Without exception it was found that the continuously aerated cultures notably surpassed the non-aerated not only in the total amount of plant material produced but also in the character of the growth and general appearance of the plants at each of the two pH levels employed. The marked influence of aeration is clearly shown by the ratios between the average yields produced by the aerated and the non-aerated cultures as given in table 4. These ratios

TABLE 4

Green and dry weights of 60-day-old tomato plants grown with and without artificial aeration and at two pH levels

	GREEN WEIGHT PER CULTURE		RATIO AERATED / NON-AERATED	DRY WEIGHT PER CULTURE		RATIO AERATED / NON-AERATED
	Aerated	Non-aerated		Aerated	Non-aerated	
	gm.	*gm.*		*gm.*	*gm.*	
pH 4.0	397	189		28.1	17.2	
	323	163		24.2	14.3	
	364			30.4		
	353			28.8		
Average	359	176	2.04	27.9	15.8	1.77
pH 7.0	477	195		35.7	18.9	
	538	164		40.7	15.8	
	490			36.4		
	445			33.4		
Average	488	180	2.71	36.6	17.4	2.10
Ratio of yields:						
$\frac{\text{pH 4.0}}{\text{pH 7.0}}$	0.74	0.98		0.77	0.91	
$\frac{\text{pH 7.0}}{\text{pH 4.0}}$	1.36	1.02		1.31	1.10	

show that the average green weight yields produced by the aerated cultures at pH 4.0 and pH 7.0 were 2.04 and 2.71 times the corresponding yields produced by the non-aerated cultures, respectively, whereas the average dry weight yields produced by the aerated cultures at pH 4.0 and pH 7.0 are shown to be 1.77 and 2.10 times as high, respectively, as the corresponding yields produced by the non-aerated cultures.

Table 4 further brings out the fact that, regardless of the influence of aeration upon yields, the plants grown in the solutions at pH 7.0 always produced higher yields than did those grown in the corresponding solutions at pH 4.0. The superiority of average yields produced by the plants grown at pH 7.0 over

those grown at pH 4.0 is shown by the ratio values given in the last horizontal line of the table.

This relation between yields and pH of the growth media is in very close agreement with the corresponding relation between average rates of total nitrogen absorption (NH_4—N plus NO_3—N) and pH of the growth media as shown in table 3. Thus it appears that the total vegetative growth made by these plants is, in a measure at least, determined by the rates at which the plants absorb nitrogen, regardless of the factors which influence these rates.

The difference in appearance between the continuously aerated and the non-aerated plants is shown by the photographs of plate 1, which were taken more than two weeks before the time of harvesting the plants. The differences at the time of harvesting had become considerably more pronounced than the photographs show.

As may be seen, one of the most striking differences appeared in the size and type of root systems which were made by the two groups of plants. The aerated cultures produced a profusion of long, white, well-branched roots which at the time of harvesting completely filled the culture jars. In contrast to this vigorous healthy condition, the roots of the non-aerated cultures failed to penetrate the solution to the lower part of the culture jars, but became localized and matted near the surface of the solution. This emphatically indicates the stimulating influence of the oxygen, which here is absorbed by the solution at the surface of the liquid only at a very slow rate.

The difference between the development of the root systems of the plants of the two groups was reflected also in a somewhat similar superiority of the aerated over the non-aerated plants in size, vigor, and general appearance of stems and leaves, which was approximately commensurate with the superiority in green and dry weight yields just noted. Large vigorous stems and an abundance of broad leaves were characteristic of the growth made by the aerated plants, while the non-aerated plants, in contrast, were characterized by small, hard, woody stems, by longer internodes, and by smaller and fewer leaves. Flowers were produced by both the aerated and the non-aerated plants, however, at practically the same time.

Carbon dioxide content of the culture solutions

The solution samples from which the carbon dioxide data were obtained by analyses were taken at the same time and in the same way as were the samples for the determination of oxygen, at the end of the 6-hour test interval. The analyses were made as soon as possible after sampling. The results of these analyses are given in table 5. All values given represent averages of not fewer than duplicate determinations.

Some attempt was made to maintain temperatures of the solutions within a reasonable range of variation during the 6-hour test periods. This was accomplished, as may be seen from the temperature record given in the table; therefore, no important significance can be attached to temperature variations, during these test intervals, as related to experimental results.

It will be observed that there is considerable accumulation of carbon dioxide in the solutions of all cultures, both aerated and non-aerated, during the 6-hour period of contact with plant roots. This accumulation is particularly pronounced in the pH 7.0 solutions, as is indicated by the ratios between the average carbon dioxide content of solutions at pH 7.0 and pH 4.0, respectively, at the end of the 6-hour experimental period. These ratios show the average carbon dioxide content of the solutions of the aerated and non-aerated cultures at pH 7.0 to be 2.07 and 1.82 times as high, respectively, as that of the solutions of the corresponding cultures at pH 4.0. Since such evidence as is available on the influence of carbon dioxide on growth responses indicates that its presence is harmful rather than stimulating, the obvious conclusion is that the superior yields of the pH 7.0 cultures over those of the pH 4.0 cultures in question were produced in spite of high carbon dioxide content rather than because of it.

TABLE 5

Carbon dioxide content of aerated and non-aerated culture solutions at two pH levels, before and after contact with plant roots during an experimental interval of 6 hours

	TEMPERATURE		ORIGINAL CO_2 CONTENT	CO_2 CONTENT AFTER 6 HOURS CONTACT WITH PLANT ROOTS		RATIO AERATED / NON-AERATED
	Aerated	Non-aerated		Aerated	Non-aerated	
	°C.	°C.	p.p.m.	p.p.m.	p.p.m.	
pH 4.0	21.3	23.3	13.3	17.6	18.0	
	20.8	22.4		15.8	26.6	
Average	21.1	22.9		16.7	22.3	1.34
pH 7.0	21.5	21.6	13.9	34.8	42.1	
	20.5	22.0		34.2	38.8	
Average	21.0	21.8		34.5	40.5	1.21
Ratio CO_2: pH 7.0 / pH 4.0				2.07	1.82	

The pronounced accumulation of the carbon dioxide of respiration in the pH 7.0 solutions may be accounted for by the strong tendency of the $CO_3^{=}$ ions or the HCO_3^{-} ions at this pH to combine with free cations to form harmless soluble carbonates. In the solutions of the lower pH this tendency is less pronounced and the accumulation of the carbon dioxide of respiration in the form of soluble carbonates would be correspondingly lower. It is to be emphasized here that the method of analyses employed in these tests, in which the test samples were acidified to liberate carbon dioxide from solution, would account not only for the free gas in solution but also for all carbonates in solution. Thus, the carbon dioxide content of the culture solutions, in this connection, refers not only to the gas in solution but also to the soluble carbonates formed as a consequence of its presence.

In general, then, it may be said that, as the natural consequence of the respiratory processes, these culture solutions in contact with the roots of vigorously growing plants tended to accumulate carbon dioxide at the same time that they were being depleted of oxygen, the prime factor which determined the degree of this accumulation being the pH of the culture solution.

Further inspection of the data of table 5, shows that the solutions of the non-aerated cultures, at the end of a 6-hour test period contained considerably more carbon dioxide than did the solutions of the aerated cultures, as is indicated by the ratios between the average carbon dioxide content of the non-aerated and the aerated solutions. These ratios show the average carbon dioxide content of the solutions of the non-aerated cultures at pH 4.0 and pH 7.0 to be 1.34 and 1.21 times that of the solutions of the corresponding aerated cultures, respectively. This clearly indicates that, undoubtedly by its sweeping action, the aerating process, which maintained the available oxygen supply of the solutions at a relatively high level against the depleting effects of the absorbing roots, at the same time retarded carbon dioxide accumulation.

However, a careful comparative consideration of all the evidence here produced reveals no significant beneficial or injurious influence of the carbon dioxide content of any of the culture solutions in question, which may be definitely related to growth yields, nitrogen absorption rates, or to the oxygen content of the culture solutions in these investigations.

In conclusion, it is to be assumed, of course, that the relative conditions, with respect to the oxygen and carbon dioxide relations, which prevailed in the culture solutions at any given instant during the growth period of the plants, were at least somewhat similar to those which prevailed at the end of the 6-hour test intervals here considered, but differed from them in degree as determined by the size and vigor of the experimental plants. It is not to be assumed, however, that equilibrium conditions could be attained during an experimental interval of 6-hours, nor is it probable that stable equilibrium could ever be attained during the growth cycle of the experimental plants with respect to absorption rates or with respect to oxygen and carbon dioxide relations in the culture solution employed in these studies. A test interval of 6 hours was arbitrarily chosen and was taken to be of sufficient duration conveniently to establish significant differences in the criteria here considered between the aerated and the non-aerated plants.

SUMMARY

Tomato plants were grown in aerated and non-aerated culture solutions at two pH levels. Analyses were made for oxygen and carbon dioxide content of the culture solutions, and the cation and anion absorption ratios were determined after the roots of the plants had been immersed in the solutions during 6-hour test intervals. The following results were evident:

The aerated culture solutions invariably showed a higher oxygen tension than did the corresponding non-aerated solutions at both pH levels. Hydrogen-ion concentration, as such, had no apparent influence upon the oxygen tension of the solutions.

Aeration produced a marked increase in the rates of absorption of cation, anion, and total nitrogen from the culture solutions, over the corresponding rates from the non-aerated solutions at both pH levels.

The rates of absorption of cation nitrogen from the solutions at pH 7.0 were higher than the corresponding rates at pH 4.0. Conversely, the rates of absorption of anion nitrogen from the solutions at pH 7.0 were lower than the corresponding rates at pH 4.0.

Yields produced by the aerated cultures were approximately double the yields produced by the corresponding non-aerated cultures.

Rates of total nitrogen absorption (cation plus anion nitrogen) were slightly but consistently higher from solutions at pH 7.0 than from the corresponding solutions at pH 4.0.

Growth yields produced by the cultures at pH 7.0 were invariably higher than those produced by the corresponding cultures at pH 4.0, and these paralleled the absorption rates of total nitrogen.

Yields of plant material produced by the aerated cultures were approximately double the yields produced by the corresponding non-aerated cultures.

Accumulation of carbon dioxide occurred in all solutions in contact with plant roots. Accumulation at pH 7.0 greatly exceeded that at pH 4.0. As the result of the sweeping action of the aerating process, accumulation in the non-aerated solutions invariably exceeded that in the corresponding aerated cultures.

Carbon dioxide accumulation in the culture solutions appeared to be without effect upon growth, nitrogen absorption rates, or oxygen content of the solutions.

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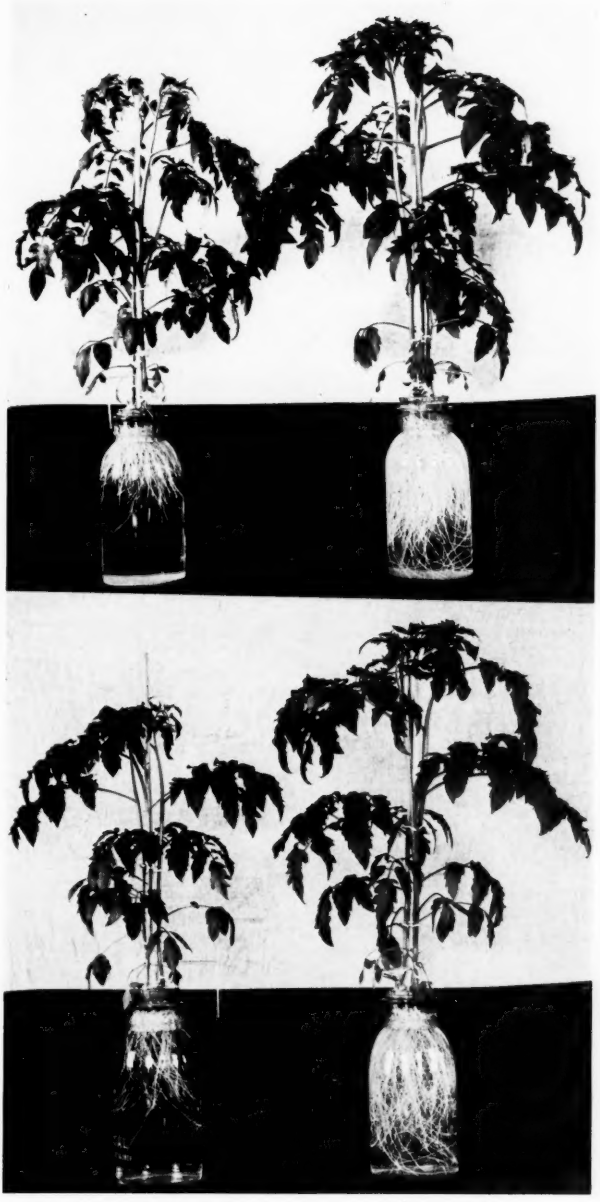
PLATE 1

EFFECT OF CONTINUOUS AERATION OF CULTURE SOLUTION ON GROWTH OF TOMATO PLANTS

Representative plants 42 days old grown in culture solutions at pH 7.0, above, and at pH 4.0, below, just before being transferred from 2-liter to 4-liter containers. Non-aerated plants at left, aerated plants at right.



THE DECOMPOSITION OF ORGANIC MATTER IN RELATION TO SOIL FERTILITY IN ARID AND SEMI-ARID REGIONS[1]

PETRUS C. J. OBERHOLZER[2]

University of Arizona

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All agricultural soils contain organic matter in varying amounts, depending chiefly on climatic factors and cultural practices. Its physicochemical nature and biological transformation have been the subject of extensive study, especially since the importance of microorganisms to soil fertility and plant growth became realized.

Generally speaking, the agricultural soils of arid and semi-arid regions are characterized by their great deficiency in both organic matter and nitrogen, but the rôle played by the organic fraction in these areas is but poorly understood. The problem has been further complicated by the advent of artificial fertilizers, which marks an altogether new era in agricultural development.

Waksman's recent book (11) is such a comprehensive treatise on the subject of soil organic matter that no attempt will be made here to review the voluminous literature. Most investigational work has been confined to the humid sections; it is the object of this investigation to study the rôle of organic matter in soil fertility of the drier regions. Chief consideration will be given to its influence on the liquid phase of the soil, to rates of decomposition as influenced by different factors, and to chemical changes produced by microbiological activities. Attempts will also be made to introduce the plant as a criterion in this respect.

EXPERIMENTAL PROCEDURE AND RESULTS

The growing plant is preëminently concerned with the soil solution; inasmuch as decomposing organic matter is believed to increase the solubility of

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various plant nutrients, the first set of experiments is an attempt to study the influence of different organic materials on the liquid phase of the soil as indicated by 1:5 water extracts.

Three calcareous soils, Gila fine sandy loam, Gila clay loam, and Pima clay, were chosen from series in the Tucson area. As organic materials were selected fresh cow manure, alfalfa (about half-bloom stage), and mature stalks of hegari sorghum. Duplicate 100-gm. air-dry samples of each soil were weighed into glass tumblers with the following treatments: (*a*) check, no treatment, (*b*) 1 gm. (air-dry and powdered) of each organic material. Moisture was brought to and maintained at the optimum, and the tumblers were incubated at room temperature (approximately 30°C. during summer). After certain intervals of time, treated and control soils were analyzed as follows: The contents of the tumblers were transferred to wide-mouthed bottles with 500 cc. of CO_2-free distilled water, placed in an end-over-end shaking machine, and shaken for one hour. The bottles were then allowed to stand for a few minutes so that the heavier soil particles could settle. Total soluble salts were determined on this supernatant liquor by means of a portable conductivity bridge, and pH measurements were made by means of the hydrogen electrode.

Following this, the suspensions were saturated with CO_2 for 15 minutes and then filtered. Phosphates were determined in the filtrates by the colorimetric molybdenum blue method, and nitrates were determined by the phenol-disulfonic acid method. The pH is expressed on 1:5 extracts; whereas soluble salts (T.S.S.), phosphates (CO_2-soluble PO_4), and nitrates (NO_3) are reported in parts per million on the air-dry soil. Since the results obtained for the three different soils were very similar, only the data for Gila fine sandy loam are given in table 1.

Evidently the various organic materials had no significant influence on the pH, which is in agreement with the findings of Stephenson (7) and others. Calcareous soils are heavily buffered on the alkaline side, hence it is conceivable that even appreciable amounts of CO_2 will have negligible effects on the final reaction.

There are only slight variations in soluble salts in the case of untreated soils; this fact suggests that microbiological activities proceed at a relatively slow rate. If organic matter is added, however, considerable changes are produced. Manure invariably caused a decrease during the first few weeks, to be followed by a gradual and continuous increase. In the case of alfalfa, the lag period, if any, is relatively short, the soluble salts increasing rather rapidly, in close correlation with increases in nitrates. Hegari showed a marked reduction in all cases; this fact can be explained by the assimilation of nitrates and their subsequent conversion to microbial protoplasm.

With respect to nitrates, it will be noticed that there is a gradual increase in this ion in untreated soils, pointing to the fact that complex organic compounds are being slowly mineralized. It is a remarkable fact that manure with a relatively high nitrogen content (1.90 per cent) should show a lag with respect

TABLE 1

Effect of organic matter on aqueous (1:5) extracts of gila fine sandy loam

TIME	pH	T.S.S.	PO_4(CO_2-SOL.)	NO_3
weeks		*p.p.m.*	*p.p.m.*	*p.p.m.*
		Check, no treatment		
0	8.60	375.0	13.50	50.6
1	8.69	757.5	13.50	49.3
2	8.67	605.0	14.00	54.6
3	8.73	580.0	15.60	83.7
5	8.71	455.0	13.20	138.5
8	8.56	680.0	11.50	116.5
12	8.61	617.5	15.60	180.0
20	8.75	605.0	20.00	240.0
		Plus 1 per cent manure		
0	8.68	632.5	53.0	72.0
1	8.59	637.5	61.5	14.0
2	8.68	560.0	59.7	10.1
3	8.71	570.0	59.0	24.0
5	8.71	570.2	57.5	81.8
8	8.52	740.0	54.0	120.0
12	8.59	795.5	72.5	257.0
20	8.60	920.1	90.0	360.1
		Plus 1 per cent alfalfa		
0	8.23	1130.0	9.25	36.0
1	8.49	950.0	10.44	75.0
2	8.38	1220.0	11.88	313.0
3	8.38	1222.5	13.60	400.1
5	8.43	1330.0	12.80	514.3
8	8.32	1505.5	12.50	600.0
12	8.42	1635.0	15.0	719.4
20	8.44	1655.0	24.8	900.0
		Plus 1 per cent hegari		
0	8.44	915.0	15.00	48.6
1	8.64	592.5	17.32	8.8
2	8.71	575.0	17.50	7.0
3	8.80	602.5	16.00	0.0
5	8.78	550.0	15.51	0.0
8	8.72	620.0	14.00	0.0
12	8.78	590.0	18.50	0.0
20	8.70	580.0	22.50	1.5

to nitrification. Evidently, the nitrogen is tied up in a more or less resistant form, which must be regarded as a distinct advantage. Alfalfa, on the other hand, is nitrified very rapidly, whereas hegari conforms to the well-known principle of nitrate assimilation by microorganisms in the presence of excessive amounts of carbohydrate material.

In all these studies, the application of manure markedly increased the amount of CO_2-soluble phosphates, even without any decomposition, whereas alfalfa and hegari had almost negligible effects when compared with the untreated soils. This suggests that increases in phosphates came from their addition with the different materials and not from the mineral fraction of the soil as a result of microbiological activities. Breazeale and Burgess (2) have shown that in the presence of $CaCO_3$, CO_2 has no appreciable effect on the solubility of phosphates. Furthermore, inasmuch as phosphate availability is largely a function of pH, these results are in agreement with the fact that the different organic materials had no significant influence on the pH.

Percolation studies

It was felt that the use of 1:5 extracts might not be a sufficiently sensitive method of measuring changes in the liquid phase of the soil as a result of microbiological activities. Hence percolation studies were resorted to, Gila fine sandy loam being selected for this purpose. Duplicate 1500-gm. air-dry soil samples were placed in large percolation tubes with the same treatments as outlined for the 1:5 extracts. The soils were then leached with consecutive 1000-cc. volumes of CO_2-free distilled water after certain intervals of time, and the percolates were analyzed for soluble salts (bridge method), pH (hydrogen electrode), calcium and magnesium (soap titration method), potassium (colorimetric cobalti-nitrite method), bicarbonates (by titrating against $0.02N$ H_2SO_4, using methyl orange as indicator), and nitrates (phenol-disulfonic acid method). The results are recorded in table 2.

Tremendous increases in soluble salts, bicarbonates, and calcium are obtained in cases where organic matter was added, especially in the first percolation, which took only 12 hours. The increases are greatest for alfalfa, followed by hegari and manure, respectively. It will be shown later that this is the order in which these three materials decompose. From the data it appears that after 6 weeks had elapsed, the organic matter was incapable of supplying any more plant nutrients to the liquid phase than in the case of untreated soils.

These results are also interesting from the standpoint of the fundamental differences between humid and arid regions. Whereas in the former, the soil solution is being constantly depleted as a result of leaching, in the latter such losses are negligible. This being the case, it is conceivable that CO_2 liberated by microbial activities will not play the same significant rôle as in the case of humid regions; in fact, we will show later that the bulk is returned rapidly to the atmosphere without seriously affecting the chemical equilibrium of the soil.

Rates of decomposition of organic materials

The data obtained with percolation studies suggested rapid decomposition of organic matter under these experimental conditions. Hence quantitative studies on rates of decomposition as measured by CO_2 production were undertaken.

Triplicate 100-gm. air-dry samples of Gila fine sandy loam were placed in pint milk bottles with the same treatments as outlined previously. The moisture content was brought to the optimum, and the flasks were closed with stoppers fitted with tubes for aspiration and incubated at 30°C. At the stated

TABLE 2

Percolation studies—effect of organic matter on soluble salts, pH, calcium, magnesium, potassium, bicarbonates, and nitrates

(Gila fine sandy loam)

TREATMENT	CHECK, NO TREATMENT	1 PER CENT MANURE	1 PER CENT ALFALFA	1 PER CENT HEGARI	CHECK, NO TREATMENT	1 PER CENT MANURE	1 PER CENT ALFALFA	1 PER CENT HEGARI
	12 hours				1 week			
T.S.S. *p.p.m.*	574.0	1516.0	2470.0	2019.0	361.0	1128.0	1630.0	2236.0
pH	8.42	8.30	7.48	7.80	9.03	8.92	8.22	8.12
Ca *p.p.m.*	135	375.0	840.0	660.0	82.5	262.0	660.4	435.0
Mg *p.p.m.*	11.0	19.0	37.1	37.0	7.5	11.5	15.0	15.0
K *p.p.m.*	44.0	80.0	213.3	128.5	23.0	83.6	307.7	30.7
HCO_3 *p.p.m.*	634	976.0	1464.0	1220.0	402.0	1073.0	2488.0	1464.0
NO_3 *p.p.m.*	203.8*	293.0*	886.0*	318.9*	59.6	59.6	70.6	57.2
	6 weeks				12 weeks			
T.S.S. *p.p.m.*	415.0	240.0	570.5	273.0	273.0	203.3	485.0	216.5
pH	8.50	8.0	8.10	7.90	7.88	7.46	7.5	7.5
Ca *p.p.m.*	102.6	72.0	123.0	57.0	69.0	45.0	152.0	48.0
Mg *p.p.m.*	1.50	2.1	3.0	4.5	4.5	4.5	4.5	3.0
K *p.p.m.*	6.0	13.3	23.0	32.0	11.7	17.4	33.3	24.3
HCO_3 *p.p.m.*	195.2	165.8	122.0	185.4	117.2	80.5	80.5	104.9
NO_3 *p.p.m.*	92.4	22.0	283.8	15.4	46.9	24.0	176.0	tr.

* Includes ammonia-nitrogen.

times the flasks were connected in an aeration unit of the type described by Waksman and Fred (12). The CO_2 produced from the different samples was determined volumetrically by precipitation with excess 0.2*N* $Ba(OH)_2$, the excess base being titrated rapidly against 0.2*N* oxalic acid in the presence of phenolphthalein as indicator. The results obtained are given in figure 1.

A study of the data obtained shows that large quantities of CO_2 were liberated where organic matter was added, the order being alfalfa, hegari, and manure, respectively. In all cases, maximum production was reached at the end of the first or second day, the quantities decreasing rather rapidly after the

third day, with the exception of the sorghum, which maintained a fairly steady rate after the fourth day. These results are in agreement with those of other investigators, but larger amounts of CO_2 were produced in our studies, especially during the first few days. Attention is called to the fact that after one month had elapsed, the differences between treated and control soils were almost negligible.

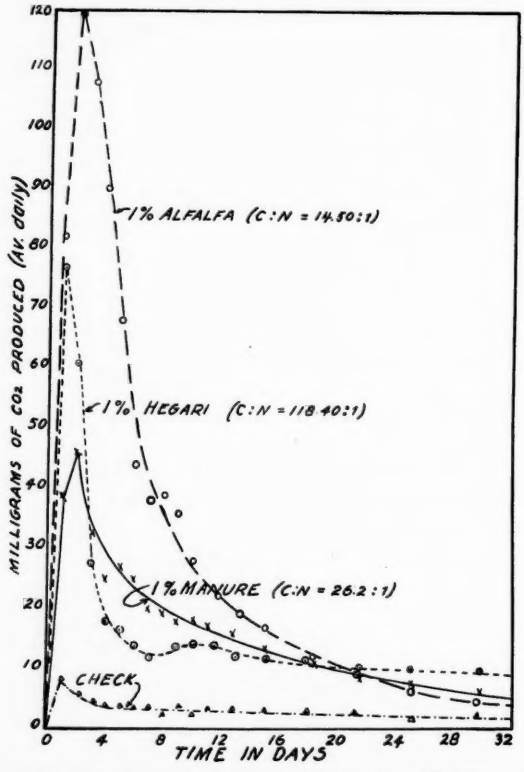

FIG. 1. RATE OF DECOMPOSITION OF ALFALFA, HEGARI, AND MANURE IN THE SOIL AS MEASURED BY CO_2 PRODUCTION

From these results it also appears that the C:N ratio is not the only factor deciding rates of decomposition, since manure, having a ratio of 26:1, decomposes more slowly than hegari sorghum with a ratio of 118:1. This is in agreement with the findings of Hutchings and Martin (3). The relatively slow rate at which manure decomposes is regarded as a distinct advantage.

Decomposition of "Pure" organic compounds in the soil

Natural organic materials consist of a great many chemical complexes such as sugars, hemicelluloses, and lignins. A study of the relative rates at which

some of the more abundant complexes decompose in the absence of others is regarded as important in order to understand their rôle in the formation of soil humus. Although it is realized that their relative rates of decomposition as "chemically pure" substances are no precise index as to their behavior when tied up in complex combinations in plants or manures, yet such data are regarded as important in the present investigation.

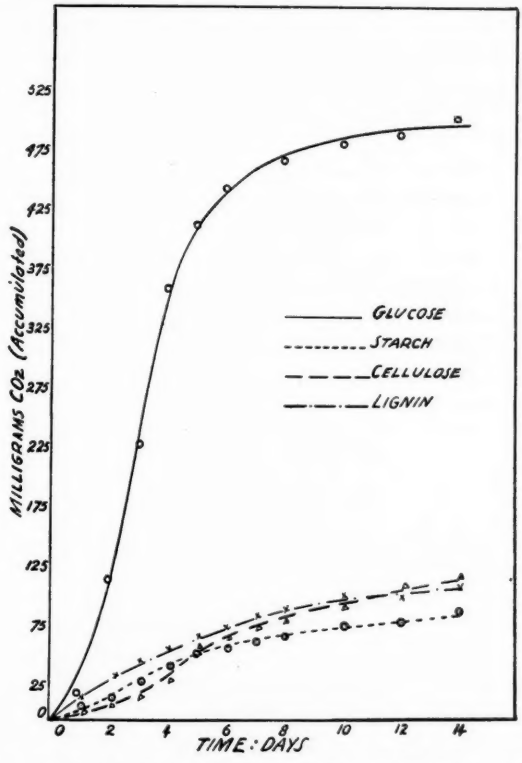

FIG. 2. RATE OF DECOMPOSITION OF GLUCOSE, STARCH, CELLULOSE, AND LIGNIN IN THE SOIL AS MEASURED BY CO_2 PRODUCTION

Duplicate 50-gm. air-dry samples of Gila fine sandy loam were placed in pint milk bottles with 1 per cent applications of glucose, starch, cellulose (finely macerated filter paper), and lignin (prepared from corn cobs [5]). Moisture was brought to the optimum, the flasks were closed with an aspiration outfit and incubated at 30°C., and the CO_2 liberated was determined as described previously. The results are given in figure 2.

If CO_2 production is taken as an index of rates of decomposition, then the order in which these substances undergo decomposition is glucose, lignin, cellulose, and starch. These data are in agreement with the findings of Mc-

George and Greene (4). Smith and Brown (6) have also shown that certain soil fungi are capable of decomposing lignins almost as fast as xylans or cellulose.

It is realized that, inasmuch as the compounds studied are essentially nitrogen-free, their relative rates of decomposition will be greatly affected by the nitrate balance of the soil. Furthermore, glucose, and possibly starch, too, may be utilized as sources of energy by organisms like Azotobacter, whereas cellulose and lignins are believed to be unavailable to such organisms. Finally, Waksman (11) has shown that the lignins are tied up in complex combinations with the proteins in humus. This "ligno-protein" complex does, however, undergo slow decomposition by microörganisms.

Influence of moisture on the decomposition of organic matter

Moisture is probably the most important single limiting factor affecting the agricultural development of arid and semi-arid regions. This applies not only to final crop yields, but also to various physicochemical and biological soil properties, the latter being associated with microbial activity and humus balance. Consequently a study of the decomposition of organic matter at different moisture contents is of fundamental importance in the present investigation, and CO_2 evolution appeared to be the most sensitive method for such studies.

The experimental technique consisted of placing 50-gm. air-dry samples of Gila fine sandy loam in pint milk bottles with 1 per cent applications of powdered alfalfa used in previous studies. The following moisture contents, expressed as percentage of the water-holding capacity, viz. 35 per cent, were selected: air-dry (3.06), 15, 35, 50, 75, and 100. Up to 50 per cent, the samples were thoroughly mixed after the required amount of water had been added. The flasks were then closed with attachments for aspiration and incubated at 30°C., and the CO_2 was determined as described previously.

In order to maintain the different moisture contents, the air, after being washed with 40 per cent KOH solution to remove CO_2, was passed slowly through different concentrations of H_2SO_4 prepared according to the vapor pressure data of Wilson (16) and of Thomas (9). At the close of the experiment, moisture determinations were made on each sample. It was found that the different percentages had been satisfactorily maintained within 2 per cent. The results obtained in this investigation are given in figure 3.

From the data it is evident that negligible quantities of CO_2 are evolved from the air-dry soil. Beyond this, however, relatively small additions of moisture give rise to large amounts of CO_2, the quantities increasing up to almost complete saturation. At the optimum and toward saturation, maximum production always occurs during the first or second day, but there is a delayed maximum at the lower moisture contents with the result that relative rates are kept up at a higher level in the latter case. When total quantities after 19 days are considered, there is found a progressive increase in CO_2 production from 15 per cent of the water-holding capacity up to complete

saturation, although the differences are not very great. This is in agreement with the results of Waksman and Gerretson (13).

One factor of great importance is the relatively large amounts of CO_2 liberated at 15 per cent of the water-holding capacity, which value is considerably less than the wilting coefficient as calculated from the moisture equivalent by use of the empirical factor 1.84. This fact suggests that the microflora, during its era of adaptation, has shifted the cardinal points in its life processes to the

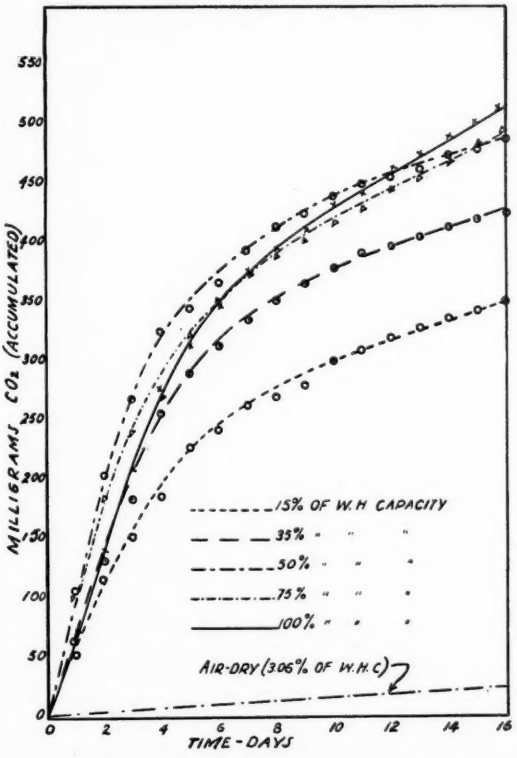

FIG. 3. INFLUENCE OF MOISTURE ON THE DECOMPOSITION OF ALFALFA IN THE SOIL AS MEASURED BY CO_2 PRODUCTION

left with respect to moisture; i.e., we are dealing essentially with a semi-xerophytic flora. At the same time, however, the specific groups of organisms appear to be capable of functioning very efficiently over a wide range of moisture contents.

Influence of temperature on the decomposition of organic matter

Next to moisture, and in some cases perhaps of even greater biological significance, is the temperature factor, these two being the chief climatic

agencies determining plant distribution and soil fertility in general. Wollny (17), Waksman and Gerretson (13), and others have shown that the rate at which organic matter decomposes increases with increasing temperature, with an optimum of around 32°C. as found by CO_2 production from soils. No data seem to be available with respect to the arid regions; hence a study was undertaken on the effect of temperature on the decomposition of organic matter as measured by CO_2 production.

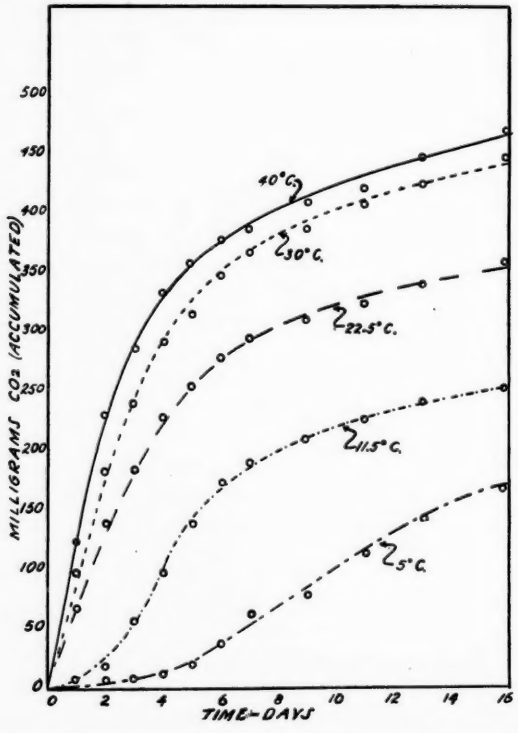

FIG. 4. INFLUENCE OF TEMPERATURE ON THE DECOMPOSITION OF ALFALFA IN THE SOIL AS MEASURED BY CO_2 PRODUCTION

The experimental procedure was the same as that outlined in the previous experiment, with the exception that the moisture was adjusted at the optimum and the flasks were incubated at 5°C., 11.5°C., approximately 22.5°C. (room temperature), 30°C., and 40°C. The CO_2 produced was again determined as described previously. The results are given in figure 4.

There is a progressive increase in CO_2 production with increasing temperature, the optimum lying somewhat above 40°C. Only small amounts are produced at 5° and 11.5°C. during the first few days, but the quantities gradually

increase, the optimum being delayed as much as one week. From room temperature up to 40°C. the largest amounts are produced during the first and second days.

From the figure it is also evident that temperature is a more important factor than moisture, but that microörganisms are capable of adaptation, hence able to liberate CO_2 over a wide range of temperature conditions. The fact that optimum production of CO_2 occurs somewhat above 40°C. suggests that, in the case of temperature, the cardinal points have been shifted to the right, approximating a semi-thermophilic microflora.

Fractionations of organic matter at different stages of decomposition

A considerable amount of work has been done with respect to chemical changes in organic matter as a result of microbiological activities. Since most of the researches have been confined to humid regions, considerable time and effort were spent in the present study in an endeavor to investigate this phase of the problem in arid regions.

The experimental technique follows: Duplicate 15-gm. air-dry samples of finely ground manure, alfalfa, and hegari (the same as used in previous studies) were weighed into small Erlenmeyer flasks, inoculated, and brought to the optimum moisture content (approximately 200 per cent) with a 1 per cent suspension of Gila fine sandy loam; the flasks were incubated at 30°C.; and the moisture was kept at the optimum. After certain intervals of time, fractionations were made on the residual material according to the method outlined by Waksman and Stevens (14). Total organic matter is designated as the residual material obtained by weighing after the required intervals of time had elapsed. The results obtained are given in figures 5, 6, and 7.

There is a rapid destruction of organic matter, the relative rates of decomposition being in agreement with the evolution of CO_2 previously reported. Evidently, as has already been pointed out, the C:N ratio is not the only deciding factor in respect to rapidity of decomposition, since hegari (C:N = 118:1) decomposes more rapidly than manure (C:N = 28:1). Presumably, the nitrogen in the latter case is tied up in a rather resistant form, which must be regarded as a distinct advantage. Hutchings and Martin (3) have shown that the chemical composition of the different complexes is an important consideration: in our studies the rates of decomposition are positively correlated with the amount of water-soluble material. As was found with CO_2 measurements, decomposition processes are extremely rapid during the first few weeks, after which time they slow down rather abruptly.

The water-soluble fraction shows an interesting phenomenon: whereas there is an appreciable decrease in this constituent, especially in the case of alfalfa and hegari during the first two weeks, the amounts are in all cases kept up at a rather high level. This is in distinct contrast with results reported by Waksman and Tenney (15), where this fraction usually disappears very rapidly. An explanation for our results is to be found in active decomposition of hemi-

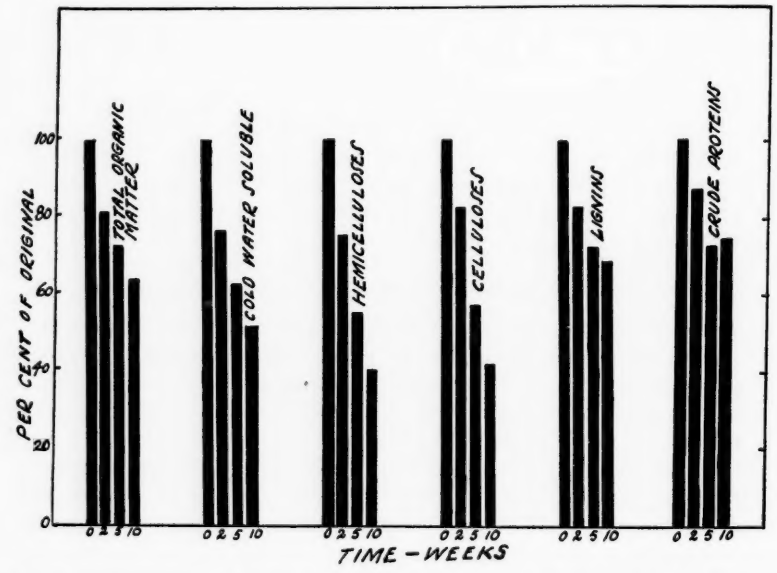

FIG. 5. DECOMPOSITION OF VARIOUS CHEMICAL CONSTITUENTS OF MANURE WHEN INOCULATED WITH A 1 PER CENT SUSPENSION OF GILA FINE SANDY LOAM

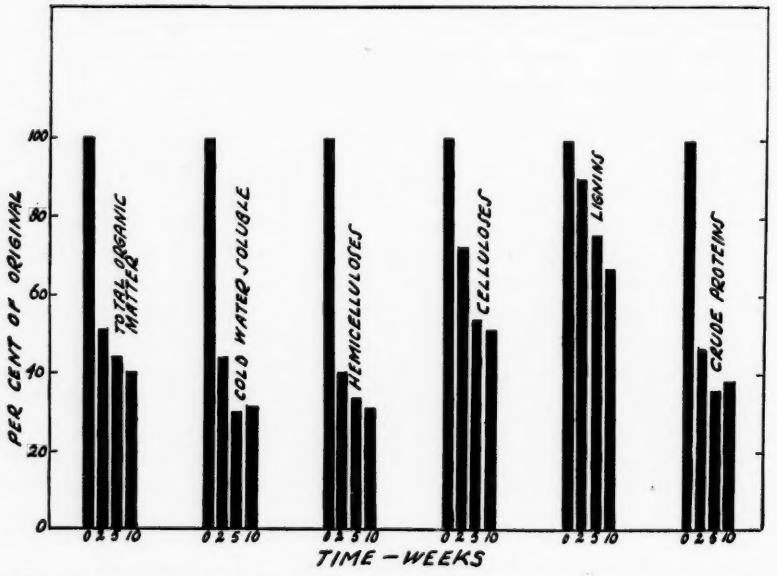

FIG. 6. DECOMPOSITION OF VARIOUS CHEMICAL CONSTITUENTS OF ALFALFA WHEN INOCULATED WITH A 1 PER CENT SUSPENSION OF GILA FINE SANDY LOAM

cellulose, cellulose, proteins, and even the lignins. In humid regions the more resistant fractions like the lignins tend to accumulate, according to Waksman and Tenney (15); our studies indicate that such is not the case.

The protein fraction likewise undergoes fairly rapid decomposition in the case of alfalfa and manure, whereas the increases found in the case of the sorghum are in part due to nitrate assimilation as well as to possible fixation by organisms like Azotobacter. In general, one might say that the trends of decomposition of the different fractions are substantially the same as those reported by other investigators (15), although it is evident that in our studies decomposition processes are carried on more rapidly and that the more resistant

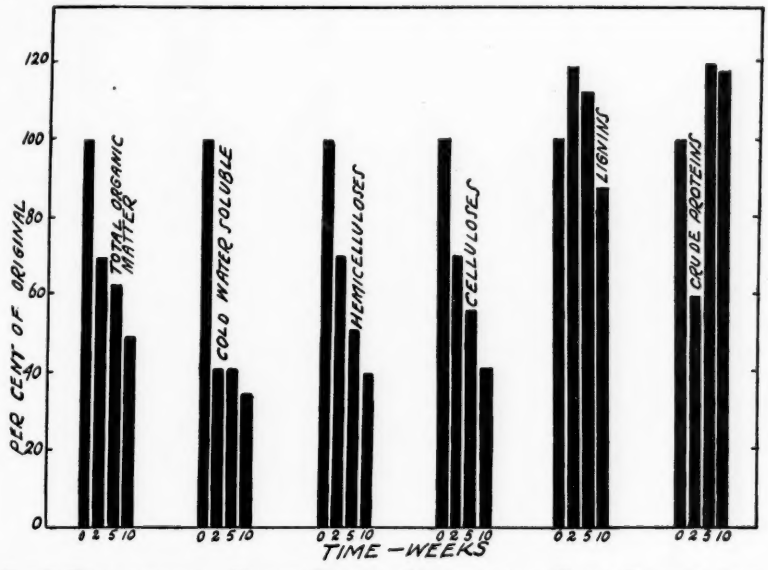

FIG. 7. DECOMPOSITION OF VARIOUS CHEMICAL CONSTITUENTS OF HEGARI SORGHUM WHEN INOCULATED WITH A 1 PER CENT SUSPENSION OF GILA FINE SANDY LOAM

fractions, notably the lignins, are also relatively rapidly attacked. This fact, no doubt, accounts in part for the fundamental difference between arid and humid regions as far as accumulation of organic matter is concerned.

Fractionation of organic matter in the presence of soils

Waksman's excellent work (11) on the fractionation of organic matter at different stages of decomposition provides a method whereby such analyses may be carried out in soils, but there are several obstacles in the way, some of a purely mechanical nature, but others, like the presence of relatively large amounts of carbonates and ferric iron, of a rather serious chemical nature. Waksman suggests removal of iron and aluminum as the hydroxides before

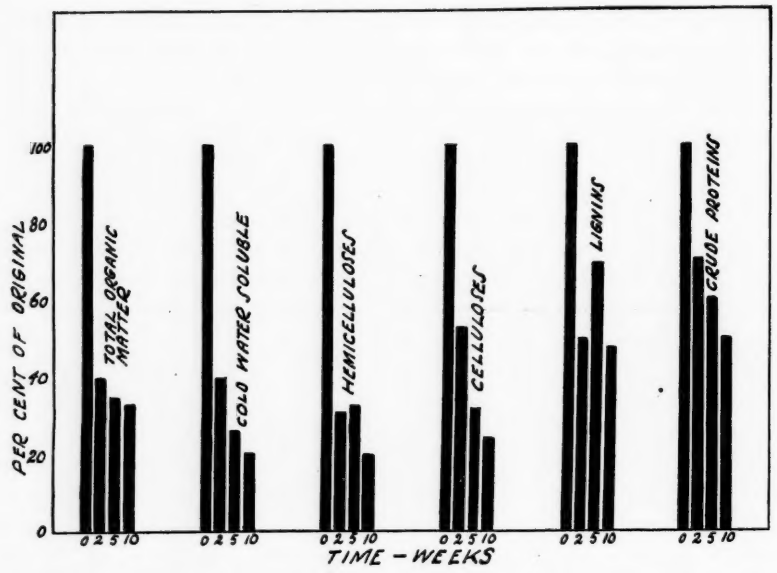

FIG. 8. DECOMPOSITION OF VARIOUS CHEMICAL CONSTITUENTS OF ALFALFA IN THE PRESENCE OF GILA FINE SANDY LOAM

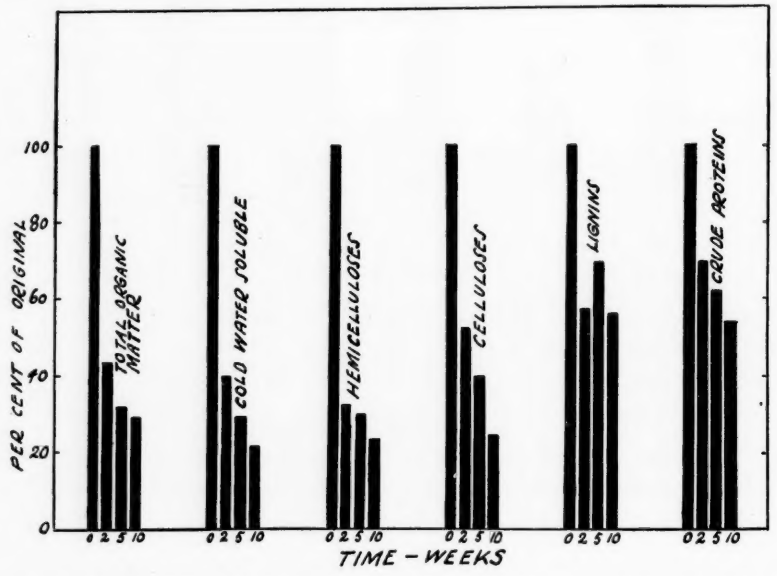

FIG. 9. DECOMPOSITION OF VARIOUS CHEMICAL CONSTITUENTS OF ALFALFA IN THE PRESENCE OF TUBAC CLAY LOAM

analyzing the acid extracts for reducing sugars but evidently does not allow for oxidation of the sugars during hydrolysis. Naturally, the final object is to develop methods that would enable us to follow the fate of the different organic constituents in actual presence of the soil in order to understand the various transformations that occur under field conditions. Considerable time and effort were therefore spent in this investigation in an endeavor to overcome some of the major difficulties already referred to.

Two soils were selected, viz., Gila fine sandy loam (9.25 per cent $CaCO_3$) and Tubac clay loam, containing no $CaCO_3$. Duplicate 30-gm. air-dry samples of each soil were weighed into glass tumblers, 10 gm. of finely ground alfalfa (about half-bloom stage, but not the same sample as used previously) was added, the moisture was brought to and kept at the optimum, and the tumblers were incubated at 30°C. After certain intervals of time, fractionations were made according to the method of Waksman and Stevens (11).

Reference was made previously to the fact that ferric iron interferes with the determination of reducing sugars. Furthermore, there seems to be no suitable method whereby it is possible to separate the iron or to render it harmless as far as oxidation of the sugars during hydrolysis is concerned. However, it is a well-known fact that the arid soils of this region contain relatively small amounts of soluble iron, even when treated with concentrated acids. Iron determinations were made on the two soils (*a*) by boiling with 2 per cent HCl for one hour, (*b*) with 80 per cent H_2SO_4 in the cold followed by dilution and prolonged boiling. In no case did more than 1 per cent iron become soluble. Further investigations showed that these amounts of iron are too small to interfere with the determination of reducing sugars in estimating the hemicellulose and cellulose fractions. No attempts were therefore made to separate the iron before analyzing for reducing sugars. The results on these fractionations are given in figures 8 and 9.

A study of the data seems to indicate that decomposition processes follow the same general trends in both soils, suggesting that $CaCO_3$ had no marked influence in this particular case. Furthermore, although the sample of alfalfa used was not the same as that in previous investigations in the absence of soil, it appears that the trends of decomposition were essentially the same in both cases. The hemicellulose and cellulose fractions disappear somewhat more rapidly in the presence of soil, whereas the protein complex is maintained at a higher level. The lignins show some variability in both soils.

Neubauer studies

The plant is the final criterion in all investigational work dealing with soil fertility. The Neubauer method, therefore, suggested itself as the most suitable for such studies.

Duplicate 100-gm. samples of air-dry Gila fine sandy loam were placed in enamelled dishes with 1 and 5 per cent applications each of alfalfa, manure, and hegari. In order to study the effect of different stages of decomposition

on the availability of phosphorus and potassium, four series were prepared, the first being started in summer (July), whereas the other three were spread over a range of about five months. Moisture was in all cases maintained at the optimum, and the samples were incubated at room temperature.

TABLE 3

Effect of organic matter on availability of phosphates and potassium—P_2O_5 and K absorbed by rye seedlings in Neubauer studies

(Gila fine sandy loam)

TREATMENT	TIME OF DECOMPOSITION	GERMINATION	P_2O_5 ADDED WITH O.M.	P_2O_5 ABSORBED	K ADDED WITH O.M.	K ABSORBED
	weeks	*per cent*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Sand blank (ave. 6)	0	88	0	29.24	0	13.00
Check, no treatment	0	77	0	31.75	0	25.01
1 per cent manure	0	88	17.20	38.10	4.0	24.85
5 per cent manure	0	89	86.00	36.70	20.0	28.00
1 per cent alfalfa	0	71	5.60	27.80	0.8	18.80
5 per cent alfalfa	0	77	28.00	29.10	4.0	26.00
1 per cent hegari	0	76	2.50	31.50	0.9	21.50
5 per cent hegari	0	84	12.50	29.60	4.5	23.80
Check, no treatment	4	65	0	28.60	0	18.80
1 per cent manure	4	66	17.20	32.00	4.0	24.30
5 per cent manure	4	79	86.00	40.20	20.0	28.40
1 per cent alfalfa	4	85	5.60	32.60	0.80	28.50
5 per cent alfalfa	4	90	28.00	35.88	4.00	36.10
1 per cent hegari	4	61	2.50	26.40	0.90	20.10
5 per cent hegari	4	91	12.50	35.25	4.50	32.90
Check, no treatment	11	75	0	33.80	0	20.00
1 per cent manure	11	88	17.20	43.15	4.0	24.50
5 per cent manure	11	87	86.00	41.75	20.0	28.10
1 per cent alfalfa	11	86	5.60	35.00	0.80	26.00
5 per cent alfalfa	11	84	28.00	41.10	4.00	28.90
1 per cent hegari	11	83	2.50	30.70	0.90	28.50
5 per cent hegari	11	92	12.50	38.50	4.50	36.80
Check, no treatment	20	56	0	28.00	0	20.00
1 per cent manure	20	78	17.20	39.70	4.00	28.00
5 per cent manure	20	78	86.00	47.50	20.00	34.50
1 per cent alfalfa	20	85	5.60	29.70	0.80	28.75
5 per cent alfalfa	20	88	28.00	38.20	4.00	41.40
1 per cent hegari	20	91	2.50	37.20	0.90	28.40
5 per cent hegari	20	95	12.50	35.00	4.50	38.40

During November all four series were simultaneously subjected to the Neubauer method, rye seedlings being used according to the standard technique. The plants were harvested 18 days after germination and analyzed for phosphates by the volumetric molybdate method and for potassium by the colorimetric cobalti-nitrite method. The results are given in table 3.

Unfortunately, the average percentage germination was very poor, although we feel that the results are still significant. It will be noticed that the soil in question is deficient in phosphates and that the organic matter, excepting in cases where no time was allowed for decomposition, invariably increased the amount of phosphates absorbed in the order manure, alfalfa, and hegari, respectively.

Phosphate determinations were made on the three organic materials; it will be noticed that increased absorption by the seedlings follows the amounts added rather closely. Furthermore, with the exception of the 20-week period in the case of 1 per cent hegari, the amount of P_2O_5 added with the different organic materials and that absorbed from the untreated soils are in excess of that absorbed from the treated soils. This presents a problem: did any phosphates come from the soil during microbiological processes or are the increases due solely to the phosphates added with the organic materials? Results obtained from 1:5 extracts showed that decomposing organic matter has negligible effects on the mineral phosphate content of the soil, and the Neubauer results seem to confirm this. Palpably, unless the increases obtained are in excess of the plant foods added, one is not justified in concluding that the organic matter had caused any increases in phosphate availability from the mineral fraction of the soil. Furthermore, the same and, no doubt, greater increases could have been obtained by the direct application of water-soluble phosphates.

The situation appears to be different with respect to absorption of potassium. In all cases, more particularly with the heavier applications and longer incubation periods, the organic matter markedly increased the availability of potassium to plants. In the case of all 1 per cent applications, the increases are in excess of the amount of potassium added with the organic matter, indicating that some potassium must have come from the inorganic fraction of the soil. Furthermore, increased absorption is positively correlated with the relative rates of decomposition of the different organic materials, indicating that the process is essentially biological in nature. It is believed that the increased solubility is brought about by way of base exchange due to interaction between carbonic acid and the potassium present in the zeolitic complex.

DISCUSSION

We may now discuss the general problem of organic matter decomposition in arid and semi-arid soils in the light of the foregoing experimental results and correlate them, if possible, with those of other investigators.

Organic matter is a natural constituent of all agricultural soils and hence is intimately associated with the numerous factors that have influenced the soil in the past and which determine its present state of fertility. Itself of complex nature, consisting of numerous types of organic compounds, it enters into physical, chemical, and biological reactions, some of which are difficult, if not impossible, to study satisfactorily. The fact that it is the home of countless

microörganisms completes a complicated picture, which has through the ages interested thoughtful men.

Its origin, chemical composition, and importance in nature have been recently well reviewed by Waksman (11), who is one of the most active workers in this field. The fundamental importance of microörganisms in keeping plant food elements in continuous circulation is probably the most important factor to be realized. But one must bear in mind that the advent of artificial fertilizers has in many respects upset the older concepts of soil fertility, a fact which is not always sufficiently well appreciated.

Scientific soil research realizes the fundamental importance of climatic conditions. Generally speaking, the soils of arid regions are characterized by their relative stability and constructive genesis, which are due chiefly to relatively porous structure as a result of predominantly physical weathering and a high degree of base saturation, chiefly with calcium. Physically then, with the exception of the black alkali lands, these soils offer much less difficulty in cultivation than do those of humid regions, where weathering agencies are chiefly chemical and destructive in nature. This being the case, it is obvious that organic matter will have totally different effects in the two regions. In the first place, humid soils contain larger total amounts due to climatic factors and plant development. Secondly, whereas a satisfactory humus balance is regarded as essential for both the physical condition and the fertility of humid soils, such does not appear to be the case for arid sections, according to the results of Theron and van Wyk (8) and Thorne (10). Finally, the nitrogen problem differs fundamentally in the two regions: humid soils are subjected to constant losses through leaching and abundant plant growth, whereas the arid regions, although generally regarded as deficient in nitrogen, seem to maintain a satisfactory balance with the assistance of active nitrogen fixation.

No physical investigations of the problem were undertaken since Alway and Neller (1), Thorne (10), and others have shown that ordinary applications of organic matter have negligible effects on the physical properties of arid soils. The chemical aspects were regarded as more important, and it was found in the present study that decomposing organic matter had no significant influence on either the pH or phosphate availability of arid calcareous soils, probably the two most acute problems in the fertility of arid soils. Of equally great significance is the fact that its influence on the content of soluble salts depends directly on its rapidity of nitrification, which leads to a very important conclusion, viz., that a very profuse liberation of CO_2 from organic matter is unable seriously to affect the highly buffered and stable system under consideration. This leads us to believe that CO_2 of microbial origin is for the greater part returned rapidly to the atmosphere, contributing but little, if anything, to the maintenance of a satisfactory supply of nutrient ions in the liquid phase. In this connection, McGeorge and Greene (4) have recently shown that sulfur may well be regarded as a suitable substitute for organic matter in arid calcareous soils, because of its beneficial effects on the pH, phosphate availability, and physical condition of these soils.

Extensive studies were undertaken on the decomposition of various organic materials, in view of the fact that few data are available for arid regions. When CO_2 production is taken as an index to rates of decomposition, it is found that, in general, the rates are higher than those reported for humid regions. Investigations on the influence of temperature and moisture on the decomposition of organic matter suggest that the former is a more important factor than the latter, but that microörganisms can adapt themselves over a relatively wide range of conditions. It was also pointed out that the particular flora under question approximates a semi-thermophilic-xerophytic one, accounting in part for the rapidity with which organic matter disappears from arid soils.

Detailed studies on the fractionation of different organic materials both in the presence and in the absence of soil again pointed to rapid decomposition processes. In general, it was found that the trends of decomposition are the same as those reported for humid regions, but there seems to be a more rapid destruction of organic matter as a whole, as well as of some of the more resistant fractions, notably the lignins. Two explanations are advanced for this fact: (*a*) a very active microflora, characteristically high in spore-forming bacteria and actinomyces, may be present and (*b*) the lignin fraction may be less stable under alkaline than under acid soil conditions. Whatever the underlying causes, it is obvious that, because of rapid decomposition processes, it is difficult, if not impossible, to build up the supply of organic matter under these conditions. It appears, therefore, that the value of organic matter in arid regions will depend chiefly on its fertilizing value and its influence on the physical condition of the soil.

SUMMARY

Aqueous 1:5 extracts on three calcareous soils using three types organic matter brought out the following facts:

Decomposing organic matter has no significant influence on the pH of calcareous soils.

Over and above its own phosphorus content, organic matter does not affect the availability of phosphates to any appreciable extent.

The influence of organic matter on soluble salts and nitrates depends primarily on its chemical nature, especially its C:N ratio. The slow rate at which manure is nitrified is regarded as a distinct advantage.

Percolation studies led to the conclusion that during the first few weeks active decomposition results in large increases of soluble salts, especially calcium bicarbonate. After six weeks had elapsed, however, the difference between treated and untreated soils was negligible.

Alfalfa, hegari, and manure decompose in the order mentioned when CO_2 production from soils is taken as an index to rates of decomposition. Larger amounts of CO_2 are produced than are reported for humid regions, and maximum production always occurs during the first or second day.

Glucose, lignin, cellulose, and starch undergo decomposition in the order mentioned when incorporated with a soil and when rates of decomposition are

estimated by CO_2 evolution. Explanations are suggested for the relatively rapid rate at which lignin decomposes, and attention is directed to the significance and importance of this phenomenon.

The rate at which organic matter decomposes increases with increasing moisture up to almost complete saturation. However, considerable losses occur even below the wilting coefficient, and it is suggested that the microbial flora has shifted to the left, the cardinal points with respect to moisture, approaching a xerophytic flora.

Decomposition of organic matter increases with temperature, the maximum being around 45°C. as found by CO_2 production from soils. Although microorganisms are sensitive to low temperatures, adaptations are possible, allowing them to function over a relatively wide range of temperature conditions. It is suggested that in the case of temperature, the cardinal points have been shifted to the right, approximating a thermophilic flora. It appears that temperature is a more important factor than moisture in the decomposition of organic matter, but obviously a combination of the two is the actual criterion.

The bulk of the CO_2 produced by microbial action does not remain in the soil, but is returned rapidly to the atmosphere, without seriously affecting the relatively stable conditions existing.

Fractionation of organic materials at different stages of decomposition shows that in general the trend is the same as that reported by other investigators. But it appears that there is a more rapid disappearance, that the water-soluble fraction is maintained at a higher level, and that the lignin and protein complexes suffer appreciable losses by microörganisms.

In the presence of soil, organic matter undergoes essentially the same trend of transformation, with the exception that the carbohydrate fraction tends to disappear somewhat more rapidly. This results in a more pronounced relative accumulation of lignin and proteins.

Neubauer investigations showed that actively decomposing organic matter is injurious to the growth of seedlings. It further appears that organic matter affects the availability of phosphates only to the extent of its own content of phosphate but markedly increases the availability of potassium from the soil.

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ON THE FORMATION OF STRUCTURE IN SOIL: I. THE STRUCTURE OF SOIL COLLOIDS

D. I. SIDERI

Institute of Fertilizers and Soil Science, Moscow, U. S. S. R.

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The ability of molecules to associate into groups, forming phases typical of a mesomorphous system, is characteristic of the aggregate condition of soil colloids.

The nematic phase (according to Friedel) is readily observed in two variants —the filamentous and the granular—in concentrated argillaceous suspensions or clay gels in a greatly swollen condition. The smectic phase is formed from water suspensions of clays under the influence of the surface tension film when the suspensions are drying up. The particles of clay are distributed in layers lying at equal distances. In clays, both phases are always anisotropic and possess a considerable double refraction. Humates, isolated from soil, also form a mesomorphous system, but with a lesser double refraction than that of clays. Their smectic phase is identical with that of clay. In some humates, as, for example, in the products of autolysis of the fungus *Aspergillus niger*, a smectic phase with a remarkably strong double refraction is precipitated. Fine quartz sand, mixed with water, after drying is distributed in rows resembling, in their relation to polarized light, the "mica system of Reusch." The phenomenon of twinning is observed not only in sand but also in the nematic and smectic phases of clays and humates and apparently it may serve for the explanation of the distortions frequently observed during the determination of the physico-mechanical properties of soils.

In many cases the behavior of colloids isolated from soil cannot be accounted for by the nature of the absorbed cations. To the most remarkable examples of such anomalous behavior belongs the instability of the suspensions of highly hydrated monovalent clays, e.g., Na-clays. In spite of the high value of the ζ-potential and their high degree of dissociation, the Na-clay sols have the ability to coagulate spontaneously even in low concentrations. It must be noted that in the latter case we are dealing not with common coagulation, i.e., with an irregular accumulation of molecules in the precipitate, but with a "directed coagulation" (35), conditioning optical anisotropy.

The present report is a communication on the spontaneous structures arising in soil colloid sols as a result of a definite distribution of molecules in groups, and on structures arising as a consequence of surface tension (22).

First of all, the ability of Na-clay to produce in a mixture with pure quartz

sand a very tenacious structure, able to resist the destructive effect not only of water, but of such alkali solutions as 0.05 *N* NaOH, appears remarkable. So is also the fact that the agregates prepared from pure quartz sand and Ca-clay possess the same "solubility" as aggregates prepared from Na-clay.

The recognition of the importance of Ca in the formation of soil structure has led to the denial of the possibility of the formation of tenacious structures (with the exception of tropical soils) outside of the ion adsorption of Ca cations by soil colloids. This conception is in contradiction to a number of facts which have thus remained without explanation. Thus, for instance, in the experiments of Tiulin on the effect of pressure on the formation of tenacious structures the saturation of kaolin with Na "alone, without applying pressure, increased, contrary to expectation, the number of water resistant aggregates in kaolin" (29, p. 47). According to the experiments of Vilensky, the tenacity of aggregates is increased in solonetz produced by treating chernozem with NaCl until a total displacement of Ca is reached (30). To the same class of phenomena, which cannot be adequately accounted for, belong also the origin of the so-called "passive slime" of Sokolovsky and the formation of the precipitate of "organo-mineral" colloids according to Tiulin, which is difficult or even quite impossible of separation.

The following remarkable observation has been reported by Nutting (13):

> An aggregate of fine and coarse particles together when moist takes on the properties of the finer particles alone. . . . The fine particles act simply as cementing material. . . . . Fine clay particles immersed in water in a thin layer between glass plates, under a microscope, may be seen gathering together in clumps. These clumps finally gather together in threads and ropes.

The author regards it as essential for the explanation of the cohesion between the particles gathered into clumps and threads to consider these as formations *possessing a fine structure, not unlike that of crystals, i.e., a structure, the separate elements of which are spatially oriented.* Indeed, observations of clay suspensions and of humate sols have shown that we are dealing here with spontaneous coagulation, resulting in the deposition of structures resembling mesomorphous formations (4, 5).

It is known that a suitable shape and size of the molecules are necessary conditions for the development of the mesomorphous state. Most investigators are of the opinion that only organic substances with rectilinear elongated molecules can be encountered in the mesomorphous state (31). Spontaneous anisotropy, determined by a definite disposition of molecules, is natural, however, also to inorganic bodies. Such is the case, e.g., of SiO_2 sols and of iron oxide hydrate reported by Quincke (20). A 3.2 per cent solution of SiO_2 purified by dialysis, after standing for 5 months, forms at the bottom of the container "about a hundred round lenses 2–3 mm. in diameter and possessing the characteristic structure of a spherulitic crystal" (20, p. 801). The SiO_2 solution having been decanted from the lenses deposited at the bottom "after a few more weeks produces new lenses" (20, p. 806). If it is subjected to

drying "the enriching in colloid solution of SiO_2, produces liquid deposits, first in the shape of thin lamellas perpendicular to the margin; later the same process is repeated at short intervals or periodically." As soon as these liquid lamellas solidify, "new lamellas are deposited normally on those formed earlier" (20, p. 808). These lamellas are made up of great numbers of "Shaumzellen" united one with another (20, p. 814), which are easily visible if a thick layer of SiO_2 is dried between a cover and an object slide. "The gel-like mass is divided into parts by fissures . . . parallel to the surface of fracture zones of large and small open Schaumzellen with confluent walls, normal to the surface of fracture . . ." (20, p. 820). Structural forms, closely resembling the aforementioned, are described by Quincke for iron oxide hydrate.

Particularly interesting is the work of Zocher (35) on the formation of structure in the sols of V_2O_5 and FeOOH, revealing a close resemblance to mesomorphous substances. Even earlier, the anisotropy of V_2O_5 sols was described by Diesselhorst and Freundlich (3), who designated such systems as anisotropic-amorphous ones. Szegvari (28) applied to the study of V_2O_5 sols the cardioid ultramicroscope with an azimut-diaphragm and found that at a certain concentration the sol particles are distributed in swarms of parallel oriented particles. The particles of such a sol are mobile and show Brownian movement. Zocher's (38) "tactosols" are formations of molecular groups arising in concentrated sols under the action of ageing, light, heat, and introduction of electrolytes; in the last case the ensuing coagulation is not a usual but rather an "arranged" one.

According to Ostwald's (15) opinion the concentrated solution of $BaSO_4$, the structural forms of which have been described by Weimarn (32), represents also a typical mesomorphous system. Weimarn finds a close resemblance between the $BaSO_4$ structures and those described by Quincke for the iron oxide hydrate, in spite of the chemical difference of the substances. Weimarn expresses the general opinion "that aggregate liquid crystalline condition is the general condition of matter."

THE STRUCTURE OF CLAYS

Vorländer's (31) view that inorganic substances are in most cases built up of spheric and not of linear molecules is not applicable to clays. For clays the tetrahedral sheets shape has become known, thanks to the investigations of Gruner (7, 8). Pauling (17, 18) established the similarity of cristallite forms of kaolinite, mica, and chloride. By analogy with substances with a leaf-like particle shape, for which the possibility of their existence in a mesomorphous state has been proved, one would think that clays also—when the shape of their crystallites is considered—may form a mesomorphous system. We know also that typical mesomorphous substances, such as stearine and palmitine acids, crystallize in the monoclinic system (34), i.e., in the same one as clay.

For the sake of obtaining a more definite idea of the matter in hand, it will be more correct to assume that clays by their nature are not mesomorphous sub-

stances, but that under certain conditions they can pass into a mesomorphous state[1] (15). Not less essential is the fact that this state of mesomorphous aggregation is acquired under the influence of water.

Sols of Na-clays isolated from various soil-forming rocks were used as the initial material for our study. Among these were loess-like loams, moraines, fluvio-glacial deposits, and Quaternary surface clays.[2] Two samples, taken from the shafts of the Moscow underground railway, represented clays from Jura and Carboniferous deposits.

The suspensions were prepared in the usual way from the rocks, ground into powder and screened through a 0.5-mm. sieve. Ca was displaced first by a saturated, then by a N NaCl solution. If the rock contained carbonates, as was usually the case, the latter were first dissolved in 2 per cent acetic acid. After the displacement of Ca, the rock was washed free of excess salt with distilled water as far as possible and then dialyzed in a parchment bag; after this, the fraction $<1\mu$ was elutriated. As the volume of the suspension was usually very large, we again coagulated the decanted suspension by a saturated NaCl solution, dialyzed the resulting precipitate of Na-clay, and thus obtained the final solution, free from salt and of approximately a 2.5–5 per cent concentration. It must be noted that in spite of a strict adherence to the rules of elutriation, we were unable to free these clay suspensions completely from very small quartz grains about 2–5μ in size, contaminating them, as could be seen under the microscope. These small quartz grains were not precipitated even when the time of elutriation was increased. To obtain clay suspensions entirely free from contamination by quartz grains we had to elutriate the suspension for a second time, diluting it greatly and increasing considerably the time of elutriation. Hence, suspensions prepared by the usual method of elutriation are always contaminated by coarse particles, this contamination being the greater, the higher the concentration of the suspension. The same thing was found by Hanley (10) in respect to pure quartz suspensions.

[1] According to Friedel, mesomorphous bodies are spontaneous and always anisotropic, whatever the conditions of their creation. Their anisotropy is manifested in double refraction, which may be very strong. Mesomorphous substances approach the amorphous ones in that they do not possess a fascicle of planes, having the properties of vectorial discontinuity, following the law of Haüy. The same substance may be encountered in two phases—the smectic and the nematic—the limits of the stability and the molecular structure of which form two intermediate points between the crystalline and the amorphous states. These phases are characterized by their absolute discontinuity.

The nematic phase ($\eta\tilde{\eta}\mu a$—filament, thread) is a condition in which the molecular axes are arranged parallel to one another. The smectic phase ($\sigma\mu\tilde{\eta}\gamma\mu a$—soap) is a condition in which the molecules are not only lying parallel to the axis but lie at equal distances in this direction. It is necessary to distinguish the mesomorphous state from mesomorphous substances; the former is not connected with the character of the chemical composition. Substances of most varying composition may assume the mesomorphous state under the influence of external conditions.

[2] The rock samples were obtained from the collection of Prof. Mirchink, to whom the author expresses his deepest gratitude for this kindness.

The X-ray investigation of all the clay samples was carried out by the powder method of Debye. Interference lines with uncertain borders were always obtained in the roentgenograms, indicating a considerable dispersity of the material, reaching at least 10^{-4} mm. The results of our measurements and their comparison with the data of other authors (7, 8, 11) show that the different minerals can be distinguished in the composition of clays: kaolinite was present in almost every sample, this mineral being probably their chief component. In several samples the chief mineral was found to be montmorillonite (bentonite) or galloisite. Besides these minerals, all the clay samples contained mica and quartz, the mica content being subject to great variations. In dilute sols clay particles can be seen at great magnification; they are about 10^{-3} mm. in size and show only slight Brownian movement. These particles are groups of still smaller ones, not larger than 10^{-4} mm., as may be conjectured from the interference lines of the roentgenograms. This tendency toward an aggregation becomes more marked with the "ageing" of clay sols. After a while, in some cases a very short time, a layer of a more concentrated sol, constituting a certain part of the total volume, is deposited at the bottom of the container. This precipitation is similar to that observed by Quincke (19) with the sols of many colloids ("the concentrated colloid solution"), and by Zocher (35) with V_2O_5 and FeOOH.

Sometimes the clay sol after prolonged standing coagulates spontaneously and an entirely clear liquid appears above a deposit, constituting about one-half of the total volume. Such a concentrated sol placed between a cover and an object slide shows a slight, diffuse double refraction, caused by the anisotropy of the colloid particles. Only those parts of the sol which are in contact with air-bubbles become optically oriented. The oriented area increases in size with time; its limits show a double refraction with an optical axis perpendicular to the longitudinal direction. Gradually the entire field of the sol is divided into areas differing in "density" from the more mobile and fluid medium surrounding them The limits of these "dense" areas become increasingly definite, and simultaneously the negative double refraction grows in the longitudinal direction. The delimitations of the structural formations are rectilinear, and their directions are almost perpendicular to one another and form a fine network within the thin layers of the gel. In the thick layers of the gel it is possible to obtain a laminated structure, which becomes clearly visible as a result of a great number of dark lines parallel to the longitudinal direction, visible also in natural light, as between the Nicol prisms. These lines show that the particles are distributed in separate layers lying at equal distances from one another, i.e., that we are dealing with the formation of the smectic phase (pl. 1, fig. 1). The structure resembles the "stries huileuses and batonnets" described by Friedel (4) and representing a modification of focal conic structures.

Such a laminated structure is typical of all of the clays tested—a total of 22 samples, all different in composition, age, and origin. All smectic bodies are,

according to Friedel, optically positive. The clays almost invariably show a negative double refraction, such as that found by Zocher and Jacobowitz (37) to exist in many smectic substances. In some cases clays show the positive phase, as for instance, when gels are subjected to freezing. It is possible that in these cases there is a gradual transition from the negative double refraction to the positive one, as was found by Zocher; this, however, could not yet be established for clays. The theory of this phenomenon is by no means clear.

The tendency of the molecules to occupy parallel positions corresponds to the condition of the least energy content. The parallel distribution in which every molecule lies along the direction of its axis represents the lowest order of the mesomorphous condition, the nematic structure. In clay sols water evaporation is the cause of the development of the smectic phase. The capillary force of the water film determines the association of separate groups of molecules into more complex formations. The excess of water ("swelling") results in the disappearance of the water film and of the smectic phase and in the appearance of the nematic phase. The boundary between these two phases is sharply marked, as has been established by Friedel. The transformation of one modification into the other is explained by the high dielectric constant of water, and this process is in complete analogy to heating, in which the fine-structural combination is also lost (25).

The nematic phase is observed in clays when they are in a greatly swollen state; this finding is similar to that of Rinne (24) in regard to the bromphenanthrene sulfonic acid. Figures 2 and 3, plate 1, show the nematic phase in a greatly swollen clay. Figure 2 shows the finely filamentous modification; figure 3, the granular one. As is well known, the nematic phase, according to Friedel (4) is represented by filamentous or by granular liquids ("liquides à fils ou à noyaux"). The nematic phase of clays shows strong double refraction with a negative optical sign.

Ornstein and Kast (14) advocate the swarm theory, according to which mesomorphous structures are not uniform over the whole macroscopic preparation. A uniform distribution exists only within small groups comprising about 100,000 molecules each. These small groups may be disposed irregularly in their chief directions, the interactions between the separate groups being weaker than those between the molecules within each such group. The arrangement of groups arises under the influence of external forces; hence, it is possible to speak of a polycrystalline structure. The independent groups may be considered as micro-crystals.

According to Stewart (27) the grouping of molecules takes place in every liquid; mesomorphous liquids are different only in that the size of their molecular groups, which Stewart calls "cybotactic groups," is greater. The arrangement of small groups into larger ones is not sufficient to cause the diffraction of X-rays (nematic bodies do not produce interference), but is sufficient to produce optical anisotropy.

It is noteworthy that Williams (33) long ago drew the attention of scientists

to the ability of clays to be precipitated spontaneously and observed the characteristic properties inherent to Zocher's "tactosols," i.e., the variability of the aggregate condition under the influence of light and heat.

THE STRUCTURE OF HUMATES

The shape of the particles of compounds of which the humates are composed is not known. Humates isolated from soil contain in most cases considerable amounts of clay and silica as contaminations. It is possible that humates are partly composed of compounds with elongated molecules, but the contaminations may change their state of aggregation.

The most suitable materials in respect to purity, i.e., minimal content of clay and silica, are humate samples isolated from peat (16), humates obtained in the decomposition of dung or hay,[3] or the products of the autolysis of the fungus *Aspergillus niger*.[4]

More concentrated sols were obtained by subjecting the humates prepared from peat, dung, and hay to evaporation in the incubator until a concentration of 6–8 per cent was reached.

In "ageing," humates do not show as high a capacity for spontaneous coagulation as do clays. Except for the products of autolysis of the fungus *Aspergillus niger*, which coagulate relatively soon, no deposit of a more concentrated sol is formed at the bottom of containers filled with approximately 0.2 per cent solutions of humates. From these signs it is evident that the tendency of humates toward spontaneous coagulation, even if it does exist, is insignificant.

Indeed, as observations show, a layer of concentrated solution of peat, dung, or hay humate between an object and a cover slide shows no double refraction either in parallel or in convergent light. Only where it borders air-bubbles does the fine limit-line show a weak double refraction with an optical axis normal to it. The same phenomenon is observed in much-swollen humate samples. When they dry, their capacity for aggregation is altered. If, for example, a drop of concentrated humate solution is dried on a slide, a picture typical of the mesomorphous condition is obtained, similar to the one described by Quincke (20, 21) for dried gels of SiO_2 and other colloids. Radial fissures, normal to the boundary, and separated zones of the drop, parallel to its border, are formed. The entire mass of the dried humate falls into separate parts; double refraction is shown only by the thin margins of the border line, their optical axis being normal to this line. The space occupied by the fissures is covered by a thin film of a weakly refracting material. Apparently we are dealing here with a similar double refraction (26), due to the depolarization of light, arising as a result of diffraction from very small microscopic or submicroscopic particles.

Peat humate, in drying between a cover and an object slide, is drawn toward

[3] The humates prepared from dung and hay were obtained from Z. J. Lein.

[4] The sample of this humate was obtained from F. J. Heltzer.

the borders into a layer of uneven thickness, due to a high surface tension. In the central areas of the preparation where the layer of the colloid is the thinnest, a network of fine filaments, similar to the one already described for clays, is formed. If the layer reaches a certain thickness, a structure of oily strips or rods is deposited, not different from that observed in clays (pl. 1, fig. 4). The double refraction is very weak, the borders of the delimiting lines of structural formation showing a greater refraction than the rest. The optical sign is positive, and the optical axis is always normal to the longitudinal direction. Similar structural forms are observed in humates prepared from dung and hay (pl. 1, fig. 5). At the rim of the cover slide, where the layer of the humate is considerably thicker, the structure in strips disappears and is substituted by forms arising from cracking (pl. 1, fig. 6), and differing from those previously described in that their delimiting boundaries acquire a rounded outline. Moreover, here we observe spherulites, producing no dark cross in crossed Nicols.

It is necessary to mention that peat and dung humates, photographed with X-rays, showed no indications of the presence of crystalline material in their composition. This circumstance cannot be regarded as the cause of the weak tendency of the humates toward mesomorphous aggregation. Cases are known in which substances amorphous in roentgenograms show double refraction in polarized light, e.g., filamentous alumina, according to the observations of Rinne (23).

Contamination by Ca salts causes humate sols to coagulate but in no way increases their aggregation as compared with Na-humates. Neither in shape nor in respect to double refraction does the smectic phase of Na-humates differ from the smectic phase of Ca-humates. Humate deposits obtained by precipitating humates with $Fe(OH)_3$ behave similarly. This observation conforms with the rule, discovered by Haber (9) and by Böhm and Niclassen (2), that, when a precipitate is formed quickly, amorphous formations arise which then are transformed gradually into crystalline ones. The humate obtained by autolysis of *Aspergillus niger* differs in its strong double refraction from the structures described. The characteristic feature of this humate is that in being dried between the cover and object slides it forms no homogeneous structure. The greater part of the preparation is occupied by a filamentous-like structure with a clearly visible distribution in layers and showing a strong negative double refraction (pl. 1, fig. 7). A strongly double-refracting fascicle of filaments is surrounded by a dark substance which cannot be rendered transparent by rotating the stage of the microscope. The appearance of amorphous substance around the smectic one may be explained by the lesser surface tension of the latter, the amorphous substance, as a result, being drawn to the borders. It is noteworthy that in convergent light this lamella seems to have a double-axis with hyperbolas passing out of the field of vision. Since the characters of the smectic phase are here distinctly pronounced and since it is difficult to suppose that we are dealing here with something else, it must be assumed, as an explanation of this anomalous structure, that the axes of the spa-

tial elements are perpendicular to the axes of the texture, as is characteristic in the case of twinning (37).

The dendrites in figure 8, plate 1, are a modification of the same stripes. Their appearance is due to the higher rate of crystallization in the presence of contaminations (1). The branches of the dendrites are surrounded by the same substance, which remains dark at rotation of the microscope stage. In a gypsum plate of the first order some parts of the dendrite structure are colored blue, while others are tinted yellow. When the stage of the microscope is rotated the former show a gradual transition from blue to yellow through the violet and red-brown tints, while the latter show the reversed course of color changes. Figure 9, plate 1, shows the spherulites, which do not produce a dark cross in convergent light and contain one or several grains of a double-refracting substance. They resemble those described by Quincke (21, p. 995). The whole area of the substance surrounding the spherulites possesses an unevenly distributed diffuse double refraction, the origin of which lies in the anisotropy of the colloidal particles of the humate.

TWINNING

Twinning phenomena are recognized by the increase and decrease of interferential coloring, periodical for different parts of the preparation (1). As observation shows, interferential coloring is regularly increased along the axis of the fascicle of filaments (pl. 1, fig. 1). While one such fascicle shows an increase in coloring, the adjacent one shows a decrease. When the stage of the microscope and the preparation with it is rotated a remarkably beautiful color change occurs simultaneously in the different sections of the preparation. These color changes show that we are dealing, not with different substances, but only with varying positions of one and the same substance.

It is interesting that twinning has been found, not only in the smectic phase of clays and humates, but also in the nematic phase during a highly swollen condition of clay (pl. 1, figs. 2 and 3).

Twinning phenomena in nematic liquids have been described by Friedel and Grandjean (6) and by Maugin (12). According to Zocher (36) the hematic phase can assume an enantiomorphous habitus, if it contains an optically active substance. It is possible that the quartz contamination, which cannot be eliminated from colloidal clay, may cause this twinning of structure. Another explanation is also possible, i.e., that clay belongs to the monoclinic system.

Bernauer (1) tested 480 substances and found that a considerable proportion of substances showing a capacity for twinning must be classed among the non-enantiomorphous ones, whereas a considerable percentage of substances showing twinning belong to the monoclinic symmetry.

Fine sand, mixed with water, gathers, when drying, into lines resembling in structure mesomorphous formations. The ranges of gathered sand are almost rectilinear, are sometimes curved, and cross almost rectangularly. The

quartz particles—right and left individuals—alternate, thus reminding one of Reusch's "mica systems." The rotation of the stage of the microscope with crossed Nicols produces no effect (pl. 1, fig. 10).

The phenomenon of anisotropy is complicated by that of twinning and is accompanied by a distortion of properties in various directions; this is probably the cause of the frequently observed deviations in the determination of the physico-mechanical properties of soils.

SUMMARY

The existence of aggregate phases in soil colloids alters essentially our conceptions regarding their behavior.

The electric properties of colloid particles, when they agglomerate into groups, are radically changed as a result of the shrinking of the ion envelope.

The properties determined by the nature of the absorbed cations are levelled out in the associated groups.

The possibility of spontaneous coagulation, explained by the prevalence of the forces of molecular attraction over those of electrostatic repulsion, is demonstrated.

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PLATE 1

Microphotographs of Clays, Humates, and Fine Sand

Fig. 1. Clay "Toida." Smectic phase. Polarized light. Magnification × 40.

Fig. 2. Clay "Toida" in highly swollen condition. Nematic phase. Polarized light. Magnification × 27.

Fig. 3. Cover clay "Makshany" in highly swollen condition. Nematic phase. Polarized light. Magnification × 27.

Fig. 4. Peat humate. Smectic phase. Natural light. Magnification × 40.

Fig. 5. Dung humate. Smectic phase. Natural light. Magnification × 40.

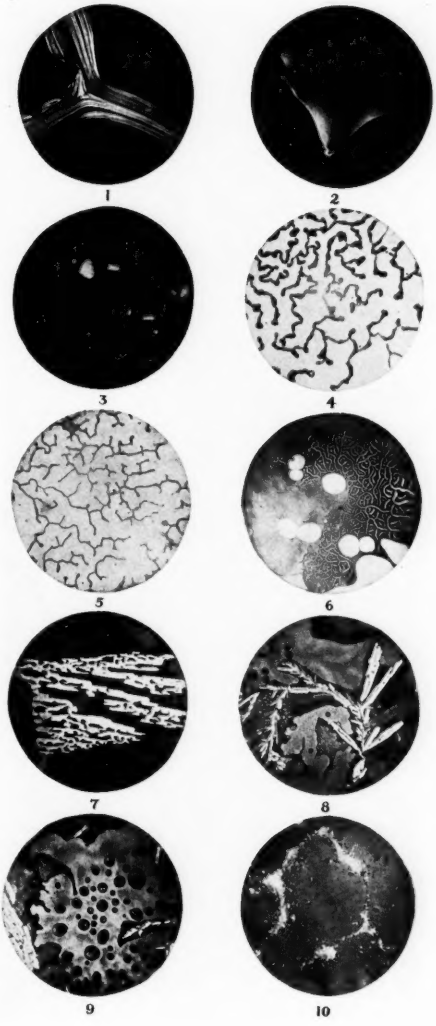
Fig. 6. Peat humate. "Figures of cracking" and spherulites. Natural light. Magnification × 40.

Fig. 7. Humate from autolysis products of *Aspergillus niger*. Smectic phase. Polarized light. Magnification × 40.

Fig. 8. Another position of the preparation shown in figure 7. Dendrite structure. Magnification × 40.

Fig. 9. Another position of the preparation shown in figure 7. Spherulites and diffuse double refraction. Magnification × 40.

Fig. 10. Rows of "gathered" sand. Polarized light. Magnification × 13.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BOOK REVIEWS

Theodor Brinkmann's Economics of the Farm Business. English Edition. Edited by MURRAY REED BENEDICT. University of California Press, Berkeley, Calif., 1935. Pp. x + 172.

Many books, monographs, and treatises have been added in recent years to the rapidly growing list of writings on agricultural economics. The present volume may have peculiar value in that it attempts to acquaint the American reader with the thinking of some of the leading agricultural economists in Europe. The editor in the preface says: "The writings of two men, Friedrich Aereboe and Theodor Brinkmann, have been especially representative of the best modern German thinking concerning the problems of agricultural economics, especially the problems of farm management. They represent an approach and point of view with which American students have not been widely familiar."

The book contains an editor's introduction; literature; three chapters, designated, respectively: General Consideration of the Types of Farming; The Levels of Intensity in Agricultural Production and The Orientation of Its Location; and Systems of Farming or The Orientation of the Locations of The Lines of Production; and an index.

It may also be noted from the editor's introduction that "One of the surprising features of Aereboe's and Brinkmann's treatment of these problems, as compared with the writings of many other German students, is the relatively small recognition of the effects of historical development on existing types of agriculture. This is, to be sure, recognized in the latter part of Brinkmann's treatment where he deals with dynamic aspects of the problem, but even there it is not fully developed. How much of the present form of agricultural production and of the present type of business unit are the result of the particular way in which the land of the United States was taken up or to the peculiar racial relationships which grew out of the era of slavery is an interesting phase of the background of farming types, and has so far had relatively little careful analysis."

Students of agricultural economics and the general reader will find much in this little book that is interesting and stimulating.

Feeds and Feeding. By F. B. MORRISON. The Morrison Publishing Company, Ithaca, New York, 1936. Pp. vi + 1050, illus. 204, tables 10.

This is the twentieth edition of a work which originally appeared in 1898. Its author was Dean W. A. Henry of the University of Wisconsin. Since few, if any, of our agricultural textbooks have enjoyed the popularity of this work,

it would be worth while to note here a portion of the brief historical record supplied in the author's preface to the twentieth edition. Dr. Morrison says:

> The first edition of Feeds and Feeding, written by Dean W. A. Henry, and published in February, 1898, was received with immediate and widespread favor by practical [illegible]kmen and by professors and students of animal husbandry. In the United States and al[illegible]a several other countries Feeds and Feeding was soon used more widely as a text book and as a reference book than any other book on livestock feeding.
>
> During the years that have passed since 1898, nineteen editions of Feeds and Feeding have been issued, several printings have been made of each of the later editions. In 1910 the book was entirely rewritten by Dean Henry with the help of the author of the present edition. In 1915 and in 1923 complete revisions of the book were again brought forth. It was necessary for the present author to assume the responsibility for these revisions, since ill health had kept Dean Henry from active work for some time. He died in November, 1932, at the age of 82 years.
>
> In the preparation of this entirely rewritten edition, the twentieth of the book, the author has spent much time during the past few years in compiling and analyzing the results of the many experiments on livestock feeding conducted in this and other countries. He has been aided greatly in this task by many investigators who have furnished him with information and with reports of experiments in advance of regular publication.
>
> In order to present adequately the results, it has been necessary to make a considerable increase in the numbers of pages in the book. To save space and also to differentiate between the information of major importance and that of only local or minor interest, some parts of the text are set in a smaller type than that of the main portion. To aid students and others in their study of the book, review questions are now included at the end of each chapter.
>
> It is the purpose of this volume to present in as simple and concise a manner as is possible the most important facts concerning the feeding, care, and management of the various classes of larger farm animals. Also, full information is given concerning the composition, use, and value of the many different feeding stuffs, especially those of importance in the United States.

The book is made up of three Parts entitled: Fundamentals of Animal Nutrition, Feeding Stuffs, and Feeding Farm Animals. The designations of the chapters are as follows: Part I: The Various Food Nutrients; The Digestion, Absorption, and Use of Food; Measuring the Usefulness of Feeds; Factors Affecting the Value of Feeds; Maintaining Farm Animals; Proteins—Minerals—Vitamins; Growth—Reproduction—Fattening; Production of Milk, Work, and Wool; Balanced Rations—Feeding Standards; and Economy in Feeding Livestock. Part II: Pasture and Hay; Silage and Soiling Crops; Legumes for Forage; Indian Corn and the Sorghums for Forage; The Hay and Pasture Grasses—the Cereals for Forage—Straw; Roots, Tubers, and Miscellaneous Forages; The Cereals and Their By-Products; Other Seeds and Their By-Products; Miscellaneous Concentrates; and Manurial Value of Feeding Stuffs. Part III: General Problems in Horse Husbandry; Feeds for Horses and Mules; Feeding and Caring for Horses; General Problems in Dairy Husbandry; Feeds for Dairy Cows; Feeding and Caring for Dairy Cows; Cost of Milk Production—Feeding Test Cows; Raising Dairy Cattle; General Problems in Beef Production; Feeds for Beef Cattle; Feed and Care of Beef Cattle—Methods and Cost of Beef Production—Veal Production; General Problems in Sheep Produc-

tion; Feeds for Sheep; Feeding and Caring for Sheep and Lambs—Fattening—Hot House and Spring Lambs—Goats; General Problems in Swine Husbandry; Feeds for Swine; and Feeding and Care of Swine. The appendix is made up of 10 tables entitled, respectively: Average Composition of American Feeding Stuffs, Digestible Nutrients, Mineral and Fertilizing Constituents, Digestion Coefficients; Estimated Net Energy Values of Feeding Stuffs; Morrison Feeding Standards for Farm Animals; Mineral Matter in Typical Feeding Stuffs and in Farm Animals; Vitamin Content of Feeding Stuffs; Weight of Concentrates and Other Feeds; Example Rations for Farm Animals; Factors and Constants for Valuing Feeds; Grain Feeding Tables for Dairy Cows; and Estimating Weights of Dairy Cattle from Heart Girths.

The author has placed his many readers under deep obligation to himself for having guided the evolution of one of our most valuable agricultural texts and reference books. He has dealt with an enormous mass of material and has known how to sift the wheat from the chaff. He has rendered a notable service to teachers, students, and farmers as well as to a not inconsiderable number of individuals not directly connected with our agricultural industry. Readers abroad, as well as those in the United States, will be ready to acknowledge their debt to him.

Biologie des Eisen—und Mangankreislaufs. By PAUL DORFF. Verlagsgesellschaft für Ackerbau, Berlin, 1935. Pp. 116, illus. 32. Price 7.50 RM.

The student of microbiology, and especially of soil microbiology, will be greatly interested in the contents of this little volume. The cycle of iron and manganese in nature is of utilitarian as well as scientific interest. The origin and scope of the work are explained by the author, who notes:

The work described in this book was carried out partly in the Biological Department of the Prussian State Institute for Water, Soil and Air Hygiene in Berlin-Dahlem and partly at the University of Lund in Sweden. Part I deals with the iron cycle. Both the regional occurrence of iron-depositing bacteria and the types of waters in which they occur in Småland and Northern Germany are described and compared; the text is well supplemented by illustrations. Samples of iron from the tropics and South-Eastern Europe are also discussed. It was found that numerous varieties of these bacteria are of very wide occurrence. In the micro-zones formed by these bacteria in the different layers of mud deposits, a large number of different varieties are contained; a table is given showing the rarer of these iron bacteria. The chemical processes involved in the bacteriological oxidation of iron carbonates are described; on the other hand a satisfactory solution of the problem of bacteriological oxidation of humates has not yet been found. In another section the technique used in research work on iron-depositing bacteria, especially the preparation of cultures (glass slides) is discussed in detail.

The section on lake and swamp iron ores is well illustrated and contains a short description of the formation, chemical composition, distribution and exploitation of such ore deposits. Special mention is made of the districts in which the author made his studies. A geological map of the floor of a Swedish lake serves to demonstrate the conditions under which the iron deposits are formed. Of special interest to those concerned with the operation of water works and mineral springs is the description of the results of the activity of such iron and manganese depositing organisms as it contains many helpful hints on the solution of many hygienic and operation problems met with such concerns. Measures are suggested for the prevention of

many difficulties connected with agricultural drainage which often result from the activity of such organisms.

The author concludes with a discussion of the nonbiogenic formation of iron and manganese deposits, with special reference to pan formation in soils, to which many crop failures are due. The book is also provided with an exhaustive bibliography containing 305 references to the current scientific literature up to 1935, and should be of interest and use not only to hydro-biologists but also to geologists, agriculturists, and those concerned with the operation of water works.

Annual Review of Biochemistry. Volume V. Edited by JAMES MURRAY LUCK. Annual Review of Biochemistry, Ltd., Stanford University P. O., California, 1936. Pp. ix + 640. Price $5.00.

This is the fifth volume of the Annual Reviews of Biochemistry. It is noted in the preface that

> Almost every field of biochemistry continues to receive extensive inquiry and the number of papers calling for careful appraisal steadily increases. Selection of the papers from which a review is to be woven, judicious weighing of the evidence presented, and synthesis of the material into a readable survey is a most difficult task. Perhaps the most unhappy feature is the necessity of leaving unmentioned a considerable number of excellent papers which temporarily must be placed aside because of the exigencies of space or because they pertain to subjects beyond the limits of the survey.

The mass of scientific data reviewed in this volume is truly enormous. The nature of the contents may be best indicated by the topics listed and the name of the author of each section. These are given herewith: Oxidations and Reductions—D. E. Green and D. Keilin; Enzymes—J. H. Quastel; X-Ray Studies on the Structure of Compounds of Biochemical Interest—O. L. Sponsler and W. H. Dore; The Chemistry of the Carbohydrates and the Glucosides—W. N. Haworth and E. L. Hirst; The Chemistry of the Acylic Constituents of Natural Fats and Oils—T. P. Hilditch; The Chemistry of the Proteins and Amino Acids—C. Rimington; The Chemistry and Metabolism of Compounds of Sulfur—V. du Vigneaud and H. M. Dyer; Chemistry and Metabolism of Compounds of Phosphorus—R. Robinson; Carbohydrate Metabolism—I. L. Chaikorr; Fat Metabolism—E. F. Terroine; Metabolism of Amino Acids—H. A. Krebs; Mineral Metabolism—E. B. Hart and C. A. Elvehjem; Clinical Applications of Biochemistry—J. P. Peters, C. L. Robbins, and P. H. Lavietes; The Hormones—E. A. Doisy and D. W. MacCorquodale; The Water-Soluble Vitamins—H. von Euler; The Fat-Soluble Vitamins—E. V. McCollum; Nutrition—A. H. Smith; Liver and Bile—A. C. Ivy and L. A. Crandall, Jr.; Comparative Biochemistry of the Vertebrates and Invertebrates—F. Kutscher and D. Ackermann; Animal Pigments—J. Roche; Metabolism of Carbohydrates and Organic Acids in Plants—W. Ruhland and J. Wolf; The Biochemistry of the Nitrogenous Constituents of the Green Plants—G. T. Nightingale; The Rôle of Special Elements (Boron, Copper, Zinc, Manganese, etc.) in Plant

Nutrition—P. Moze; Bacterial Metabolism—A. J. Kluyver; Soil Microbiology —S. A. Waksman; and Biochemistry of Fungi—N. N. Iwanoff and E. S. Zwetkoff.

It is gratifying to note that a field of science undergoing such rapid expansion has been dealt with so adequately by the editorial committee and their collaborators. Workers in the field of biochemistry will use Volume V, as they have used the other volumes, with much satisfaction to themselves. No modern library can afford to be without a set of these reviews.

Biological Effects of Radiation. 2 Volumes. Edited by BENJAMIN M. DUGGAR. McGraw-Hill Book Company, Inc., New York and London, 1936. Pp. (vol. 1) x + 1–676, (vol. 2) vii + 677–1343. Price $12.00.

This two-volume work was made possible "by financial support from the Committee on Radiation through contributions received for the radiation program by the National Research Council from the General Education Board, the Rockefeller Foundation, and the Commonwealth Fund." It is noted elsewhere in the Preface that "The 'Biological Effects of Radiation' constitutes a collective contribution that has been developed as a by-product from one of the activities of a committee now known as the Committee on Radiation, in the Division of Biology and Agriculture, National Research Council."

The topics dealt with in the several chapters and the authors are as follows: Photons and Electrons, by Karl K. Darrow; Measurement of X-Rays and Radium, by Lauriston S. Taylor; Ionization and Its Bearing on the Biological Effects of Radiation, by G. Failla; Measurement and Application of Visible and Near-visible Radiation, by F. S. Brackett; The Intensity of Solar Radiation as Received at the Surface of the Earth and Its Variations with Latitude, Altitude, the Season of the Year and the Time of Day, by Herbert H. Kimball and Irving F. Hand; Statistical Treatment of Biological Problems in Irradiation, by Lowell J. Reed; Photochemistry, by Farrington Daniels; The Effect of Radiation on Proteins, by Janet Howell Clark; Radiation and the Vitamins, by Charles E. Bills; The Effects of Irradiation on Venoms, Toxins, Antibodies, and Related Substances, by S. C. Brooks; The Effects of Radium and X-Rays on Embryonic Development, by Elmer G. Butler; Effects of X-Rays and Radium upon Regeneration, by W. C. Curtis; The Biological Effectiveness of X-Ray Wave-Lengths, by Charles Packard; The Physiological Effects of Radiation upon Organ and Body Systems, by Stafford L. Warren; Short Electric Wave Radiation in Biology, by G. Murray McKinley; Biological Effects of Alpha Particles, by R. E. Zirkle; Motor Responses to Light in the Invertebrate Animals, by S. O. Mast; The Action of Radiation on Living Protoplasm, by L. V. Heilbrunn and Daniel Mazia; Photoperiodism, by W. W. Garner; Plant Growth in Continuous Illumination, by John M. Arthur; The Effects of Light Intensity upon Seed Plants, by Hardy L. Shirley; Effects of Different Regions of the Visible Spectrum upon Seed Plants, by H. W. Popp and F. Brown; Effect of the Visible Spectrum upon the Germination of Seeds and Fruits, by William

Crocker; The Effects of Visible and Ultra-violet Radiation on the Histology of Plant Tissues, by J. T. Buchholz; Some Infra-Red Effects on Green Plants, by John M. Arthur; The Effect of Ultra-violet Radiation upon Seed Plants, by H. W. Popp and F. Brown; The Effects of Radiation on Fungi, by Elizabeth C. Smith; The Problem of Mitogenetic Rays, by Alexander Hollaender; Effects of X-Rays upon Green Plants, by Edna L. Johnson; The Effects of Radium Rays on Plants, by C. Stuart Gager; The Light Factor in Photosynthesis, by H. A. Spoehr and J. H. C. Smith; The Influence of Radiation on Plant Respiration and Fermentation, by Charles J. Lyon; Growth Movements in Relation to Radiation, by Earl S. Johnson; Chlorophyll and Chlorophyll Development in Relation to Radiation, by O. L. Inman, Paul Rothemund and C. F. Kettering; Radiation and Anthocyanin Pigments, by John M. Arthur; Effects of Radiation on Bacteria, by B. M. Duggar; The Effects of Radiation on Enzymes, by Harold A. Schomer; Induced Chromosomal Aberrations in Animals, by Theodosius Dobzhansky; Radiation and the Study of Mutation in Animals, by Jack Schultz; Induced Mutations in Plants, by L. J. Stadler; Induced Chromosomal Alterations, by T. H. Goodspeed; Induced Chromosomal Alterations in Maize, by E. G. Anderson; and Biological Aspects of the Quantum Theory of Radiation, by John W. Gowen. The book contains also a subject index and an alphabetical list of contributors.

The editor and his collaborators have done their work faithfully and effectively. They have made a distinct and important contribution in a field of science which is attracting increasing interest. They have laid the foundation for further growth in the body of knowledge for which they have labored to the advantage of all students of the subject.

An Outline of Biometric Analysis. By ALAN E. TRELOAR. Burgess Publishing Company, Minneapolis, Minnesota, 1936. Pp. 193. Price $3.10.

The specific nature of this treatise is indicated, in part in the author's preface. The following may be quoted:

> The present outline aims to provide in the simplest possible terms, the introductory reasoning that may lead to the establishment of that knowledge and conviction. It deals with principle rather than theoretical detail. The discussion of Part I is devoted to the simplest cases of univariate and bivariate frequency distribution, and purposefully avoids as far as possible the controversial topic of "small sample" analysis. Parts II and III are concerned with the subject matter of two more advanced courses dealing with correlational analysis and statistical estimation. These latter parts assume that an increased facility in algebraic reasoning, and a greater willingness to accept the results of calculus derivations, spring from the assimilation of the earlier discussions.

The contents are arranged in three parts. The individual chapters are designated, respectively: Part I—Introductory; Quantitative Data and Symbolic Representation; The Distribution of Frequency; The Measurement of Type; The Measurement of Dispersal; Moments and Frequency Curves; The Errors of Random Sampling; Probability and the Binomial Series; The X^2 Cri-

terion; The Coefficient of Correlation; Rectilinear Regression; The Error of Estimate; and Significant Correlation. Part II—Differences and Correlation; Partial Correlation; Multiple Rectilinear Prediction; The Correlation Ratio; Curvilinear Regression; The Coefficient of Contingency; Correlation from ($2xm$) Fold Tables; Correlation Between Ranks; and Intra-Class Correlation. Part III—Introductory; The Distribution of Means; The Distribution of Differences Between Means; The Distributions of s^2 and of s; Fisher's z Distribution; "Student's" Z (or t) Distribution; The Joint Distribution of $\bar{x}$ and s; The Analysis of Variance; and The Distributions of Correlation Coefficients.

In addition there are an appendix containing four tables and a summary of formulae. This is followed by an adequate index.

The rapid increase in the importance of statistical data in the various fields of agricultural science will emphasize the helpfulness of this work. It offers distinct values to the teacher and student, as well as to the investigator, of biological phenomena.

Solon Robinson—Pioneer and Agriculturist. Volume I. 1825–1845. Edited by HERBERT A. KELLAR. Indiana Historical Bureau, Indianapolis, 1936. Pp. xxv + 582, illus. 10.

This publication represents Volume XXI of the Indiana Historical Collections. In his foreword to the book, Christopher B. Coleman notes:

> The inception of the publication of writings of Solon Robinson came about in 1926 at a meeting of the American Historical Association at Rochester, New York. In the session devoted to an "Agricultural Who's Who in the Ante-Bellum Period," the statement of Herbert A. Kellar that Robinson was the most important agricultural writer of that period in the North met with general acceptance. Robinson's extensive travels in the South, also, his observations upon the plantation system, and his efforts to work up common agricultural interests in both sections were of national significance. The late Ulrich B. Phillips, of Yale University, whose judgment upon such matters commanded the greatest respect, in expressing his agreement with Mr. Kellar, urged the publication of Robinson's writings. His interest in the project continued down to the time of his last illness. There have also been recurrent suggestions in the Agricultural History Society that such a publication would be a valuable contribution to the history of agriculture in the United States.

Reference may also be made to the preface by Herbert A. Kellar. He says:

> In the course of a long and active interest in the history of American Agriculture, I have been impressed with the personality and achievements of a group of men living for the most part in the ante-bellum period, whose whole-hearted and unselfish devotion to the cause of agricultural improvement won them national recognition in their own time. As a nation we shall be fortunate if in future we can point to the equals of such men as John Taylor of Caroline, John S. Skinner, Edmund Ruffin, Jesse Buel, Martin W. Philips, Thomas Affleck, Andrew Jackson Downing, John S. Wright, Benjamin P. Johnson, and last, but not least, Solon Robinson. Biographies of Taylor have been written by William E. Dodd and H. H. Simms, and Ruffin has his chronicler in Avery O. Craven. I take pleasure in presenting Solon Robinson of Indiana. You will find that he was a man of parts.

The book contains a list of documents dated within the period 1825 to 1845. These portray effectively the economic and social status of the United States, which at that time was still in its pioneering period. The reader will gain a distinct understanding of the environment under which the agriculture, commerce, and industry of that region evolved, the obstacles which had to be overcome, and the atmosphere under which generations of men and women grew into greater regional and national responsibility.

Sulfuric Acid Manufacture. By ANDREW M. FAIRLIE. American Chemical Society Series. Reinhold Publishing Corporation, New York, 1936. Pp. 669, figs. 187, tables 67.

Sulfur, sulfuric acid, and their derivatives are products of major concern to agriculture, industry, and commerce. They occupy an important place in the import and export business of many countries. For this reason, this book may be accepted as having large and peculiar value.

It is noted in the general introduction that "By arrangement with the Inter-allied Conference of Pure and Applied Chemistry, which met in London and Brussels in July, 1919, the American Chemical Society was to undertake the production and publication of Scientific and Technologic Monographs on chemical subjects." It is noted elsewhere that "The publication of these books marks a distinct departure in the policy of the American Chemical Society inasmuch as it is a serious attempt to found an American chemical literature without primary regard to commercial considerations."

It may also be noted from the preface that "Foreign books on sulfuric acid manufacture have been pronounced deficient in the space alloted to the consideration of American practice. This book may be criticized abroad on the ground that American practice has been stressed too much. However, it is believed that in the contact processes American practice, during the period 1925 to 1935, has progressed farther than the foreign practice, and that there is justification for emphasizing the advances made in the United States."

The contents of the book are best indicated by the names of the chapters which follow: Historical; Chemistry and Theory Relating to Sulfuric Acid Manufacture; Construction Materials; Production Materials; Burners, Roasters and Furnaces; Burner- or Furnace-Gas; Nitration Processes—Methods of Nitration; Glover Tower; Lead Chambers and Chamber Substitutes; Recovery of Nitrogen Oxides; Auxiliary Equipment of a Nitration-Process Plant; Complete Plant Design—Operation of a Nitration-Process Plant; Purification and Concentration of Sulfuric Acid; Contact or Catalytic Processes. General Discussion; The Composition of Burner- or Furnace-Gas. Cleansing, Cooling and Drying the Gas; Blowers, Preheaters, Heat-Exchangers, Converters; Catalysts; Comparison of Platinum and Vanadium Catalysts; SO_2-Gas Coolers; SO_2 Absorbers, Oleum Manufacture, Miscellaneous Contact-Process Equipment; Complete Contact Plant. Operation. Methods of Control of Process; Special Types of Contact Plant, Individual Installations; Mixing and

Shipping Sulfuric Acid, Hazards and Safety Measures, Costs and Cost-Accounting, To Buy or To Build, Choice of Process, Trends in the Industry. The appendixes contain a wealth of timely and useful information, and the index is an adequate one.

Dictionary of Terms-Relating to Agriculture, Horticulture, Forestry, Cattle Breeding, Dairy Industry, and Apiculture in English, French, German, and Dutch. Compiled by T. J. BEZEMER. The Williams & Wilkins Company, Baltimore, 1935. Pp. vii + 294.

The terminology in the fields named in the title is growing rapidly. New terms are being introduced to a point where the student of agriculture and of the biological sciences is very much in need of new information and of clear definitions. As is noted in the publishers' preface:

> Students of Agriculture, Horticulture, Forestry, Cattle Breeding and those engaged in the Dairy Industry are repeatedly obliged to consult textbooks or works of reference in a foreign language. In searching for a translation of the technical terms used in their special subject of study they find that the standard dictionaries, if they give the word at all, fail to provide a satisfactory equivalent. This applies not only to technical terms, but also to common words relating to Agriculture, Horticulture, Forestry, Cattle Breeding and the Dairy Industry which are not used in their common or general sense, but with a more restricted or specialized meaning.

In the foreword by the editor, it is noted:

> As appears from the Publishers' Preface, this work is the first dictionary of its kind in this field, and it is as such it should be judged by the users. The great number of auxiliary sciences which have to be studied for the practice of agricultural economy rendered it imperative to make a selection of the words to be included in the work.

This dictionary is to be commended to a wide circle of students. It will be found useful by teachers in our universities, colleges, and secondary schools; by thousands of workers in the field of agricultural extension; and by the great agricultural constituency who are engaged in the production of crops and the raising of farm animals.

JACOB G. LIPMAN.